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THE MAKING OF
CHEMISTRY

THE MAKING OF CHEMISTRY

BY

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PREFACE

THE history and development of chemistry represents a vast panorama, encyclopedic in its content and profuse in its details. In order to write a book for the layman which would impart some of the spirit of the science, which is the aim of this book, I have kept two objects in view. First, to stress leading principles only, the discoveries and hypotheses centering around the few personalities upon which the progress of the science has depended; secondly, to avoid, in so far as possible, technical expositions which embarrass and mislead the non-scientific reader, and yet to explain, within certain obvious limits, the significance of such hypotheses and discoveries.

Wherever possible, the story centers around the leading personalities responsible for great chemical discoveries, and an attempt is made to show that what is usually called "abstract" scientific research is the mother of every scientific advance, pure or ap-

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plied, in the laboratory or in industry. The recluse of the Middle Ages, shut in in the monastery and shut out of the outside world, has become the scientist of our day, still shut in, but in the laboratory. By threads, sometimes visible, sometimes not always apparent, he shapes much of the intellectual and all of the material development of our times.

My thanks are due to Professor W. L. Prager, Mr. P. M. Apfelbaum, and Mr. C. A. Marlies, for having read the manuscript.

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CHAPTER I

THE STONE AGE

GEOLGY and archeology have given us eyes to peep into a past which antedates any historical records we possess, and astronomy directs our eyes to a universe which was in action long before the earth had become a separate planet. But just now our interests do not lie in the formation of solar systems, nor in the birth and early fruition of the earth, nor even in the period in which reptiles and mammals other than man appeared; but in the time, to be counted in many thousands of years, which began with the Pliocene and ended with the Neolithic period, and which left us the Java man and the Heidelberg jaw and the Piltdown skull and the Cro-Magnons, and which produced tools and ornaments and weapons made of flint and ivory and bone and, finally, metal. During this period animals were domesticated and plants cultivated; the plough was invented, and so was the wheel; the art of the potter came into existence, as did mining for gold and silver.

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Where does our chemistry start? Not anywhere, strictly speaking. To be sure, Nature herself, during the course of countless ages, had shown many chemical transformations even before man appeared, but we are here concerned with chemical processes deliberately employed by man, and during the Stone Age, or perhaps earlier, it seems reasonable to attribute to man the discovery of making fire.

Fire, which is accompanied by intense heat, brings about chemical changes which would otherwise remain unknown. Few substances react without being heated; on the other hand, all chemical reactions are either initiated or, still better, intensified, with the aid of heat.

Chemistry, then, which deals with changes which matter undergoes under certain given conditions, has a history which probably dates back to some period in the Stone Age when, according to our authorities, fire was invented (or discovered, or stumbled upon). It was this invention which probably led to a better knowledge of copper, and which certainly laid the foundations for our knowledge of bronze and iron, so that the age following the Stone Age became the Bronze and the Iron Age.

CHAPTER II

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THE period covered in this chapter is somewhat over 4,000 years—roughly, from 4000 B.C. to 200 A.D. This is still a vast stretch, but compared to what had gone before, it is quite insignificant. Within these years are included the first authentic written records, at one end, and the development of an active alchemistic period, at the other. Egypt, which has lately given us Tutankhamen and many a startling revelation of a distant past, is selected by our historians as the mother of our civilization, though sometimes it is forced to share this honor with Babylonia. The very word “chemi” means “Egypt,” and some have traced the word “chemistry” to it; though upon this score much uncertainty exists.

Excavations and written records supply us with many details of the activities of the human race during these 4,000 years; and, naturally, the records become more numerous and the details more minute as we approach the close of this period. We watch

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the rise and fall of Egypt, of Babylonia, of Assyria and of Persia; we follow, with some hesitation, the uncertain steps of progress in China and in India; we trace, with unbounded admiration, the development of the Greek commonwealth and the rise to power of imperial Rome; we watch religions start and spread in the histories of Confucius, Buddha and Christ; and we approach a twilight zone of civilization as we end the second century of the Christian era and meet with the half-tamed hordes of Aryans in Central and Northern Europe.

Throughout this period we find thinkers of the highest order: the minds of Plato and Aristotle are the glories of mankind for all time. We even have an astronomy which flowers in the teachings of Ptolemy and a mathematics and physics which receive an impetus from the labors of Euclid and Archimedes. But, taken as a whole, experimental science as we understand it to-day, is non-existent. The men of talent are the speculators who evolve theories upon theories, and who regard the handling and the mixing and the heating of materials as an occupation worthy of a lower order of beings. Discoveries in experimental science—and, more particularly, dis-

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coveries in chemistry—are of an accidental, empirical, practical kind, fostered largely for financial reasons, and made by men with a business turn of mind. Whereas, in experimental science in our day, the speculator and the experimentalist are one and the same, in the period under discussion they were very sharply divided; and to trace the origin of our science, we must consider both of them.

What might be termed the “practical” chemical knowledge of the Ancients included the recovery of some of the common metals from their ores, the making of glass and pottery, the art of dyeing, and the process of fermentation. The Ancients were acquainted with such metals as gold, silver, copper, tin, lead and iron, which means that since not all these metals are found native as such, the people must have been familiar with several metallurgical processes. Red, black, blue and white pigments were known, and wool was dyed and various shades of color produced with the help of mordants. Pliny records a wine of such high alcoholic content “that it takes fire on the application of a flame.” Glass was known from prehistoric times.

It is quite probable that what historical remains

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we have are insufficient justly to evaluate what was actually known. There seems some reason to suppose that a number of discoveries and inventions of a fairly contemporary period to our own were, in reality, things known to the Chinese in a more remote period and then buried and forgotten in succeeding ages. It is unquestionable that our knowledge of the past would have been more extensive and more exact if man's passion for destruction had not led conquerors to destroy such precious deposits as the Alexandrian library. Much of what we do know we owe to a chance discovery of a Swedish vice-consul stationed in Alexandria early in the nineteenth century. He came across an Egyptian papyrus manuscript, written presumably in the third century A.D., but embodying the accumulated knowledge of many centuries. The manuscript was sold to the Dutch government and it was eventually deposited in the library of the University of Leyden, whence it became known as the Leyden Papyrus. Philological and chemical students have since translated the manuscript into various European languages.

The Leyden Papyrus embraces various recipes dealing with metal working, the making of alloys,

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dyeing material, imitating precious stones, etc. It is essentially a trade manual written by a practical man for practical ends. It bears the same relation to the science of chemistry that a modern cookbook does to the science of nutrition. It does not lack trade-names to make many of the experiments described difficult, if not impossible, to interpret. Occasionally the author indulges in weird flights such as became only too common at a later period. We are told, for example, that a pearl may be whitened by causing it to be swallowed by a cock, then killing the bird and recovering the pearl. On the other hand, there are quite intelligible descriptions of how to gold plate metals and how to dye cloth.

That the Leyden Papyrus represents the knowledge of accumulated ages is made evident when we compare its contents with the more or less incidental allusions to chemistry in the writings of earlier authors, such as Pliny; but where these practical arts originated, whether in China, in India or in Egypt, remains a mystery. This much seems certain: that the Greeks and the Romans inherited from the Egyptians the knowledge they possessed. Seemingly equally certain is the view that during this period there was

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no extensive attempt to transmute "base" metals into gold, such as became the ruling passion of the alchemists in a succeeding age.

Since chemistry deals with the material make-up of the universe, it is not surprising that the philosophers of the past should have given attention to this aspect of the subject. To them this examination of matter was but a phase in the grander scheme of an attempted interpretation of the cosmos. Here now we approach the philosophy of chemistry, to be sharply distinguished from the cookbook type of chemistry as exemplified by the Leyden Papyrus. But it should not be overlooked that suggestive as the theories of the philosophers were—and actually proved to be in a later age—for the time being, and for many, many years afterwards, the theories remained just theories. The divorce between the philosopher and the experimental worker was complete. The language of the philosopher was quite "Greek" to the experimental worker, who was a man with inferior abilities in learning and understanding; nor would the philosopher stoop to handling, mixing and heating materials. Had the two combined their efforts much might have been gained. As it is, we merely get one or two germs of fruitful ideas from the thinkers, and an unas-

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sorted, indiscriminate array of facts and observations from the hand-worker.

Now, what were the essential contributions of the thinkers in so far as the development of chemistry is concerned? They were two in number: that matter is made up of very small particles called atoms; and that everything in the material universe can be traced back to four "elements," earth, air, fire and water. It would seem that Hindu and Greek philosophers developed such ideas independently of one another; but our records are more complete with regard to the Greek contribution; and we know that beginning with Thales in the seventh century B.C., and passing in review Anaximenes, Heraclitus, Empedocles, Democritus, Plato and Aristotle, the notion of the four elements and the idea of an "atomos" had become fairly well fixed.

At this stage it might be remarked that the atom idea, reborn in a period contemporary with our own, was destined to prove one of the most fruitful hypotheses advanced in chemistry; whereas the so-called four elements, earth, air, fire and water, were in the last hundred and fifty years shown to be no elements at all, in the sense in which we moderns use the word "element." But of this, more later.

CHAPTER III

ROGER BACON AND THE SCIENTIFIC METHOD

THE rapid rise of Christianity in Europe corresponded with the rapid decline of the Roman Empire and a corresponding ascendancy of races to the north of Italy. Throughout the centuries which were to follow, every intellectual activity in Europe was colored by church doctrines. Some activities, such as those dealing with art, suffered little, if at all: the remains of medieval churches bear eloquent tribute to the genius of the workers of those days. Other activities, particularly those dealing with the physical sciences, suffered incalculably. It was during this period that alchemy thrust its head into the foreground. The church mystics invaded the laboratory of the alchemist and translated his experiments into meaningless phrases. The philosopher's stone, with which any desired change could be accomplished, was eagerly sought for, and announcements of its discovery were frequently made. Misinterpretations of metallurgical processes gave rise to a belief in

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the possibility of converting "base" metals into gold, and Europe swarmed with men who have their modern equivalent in the counterfeiter.

Yet in other fields, during these years (roughly from 200 A.D. to the discovery of America at the end of the fifteenth century) men were active and often constructive. Mohammed gathered a considerable portion of the earth's people into his fold. Charlemagne spread his rule over Europe. Abélard and Aquinas lent honor to the word "scholar." Universities were founded and a love of learning fostered. The Magna Carta expressed faith in representative government. Italy of this period gave to the world Dante and Petrarch in letters and da Vinci and Raphael in arts.

Science, however, made little progress. Were it not for an Alexandrian school and Arabian scholars who followed their countrymen into conquered Spain, even the labors of the past would have been forgotten by the Europeans of that time. It is true that notable inventions of one kind or another sprang into being, as it were, from time to time. Windmills, the rudder, the mariner's compass, chimneys, window glass, eye glasses, magnifying glasses, gunpowder,

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mechanical clocks, glass mirrors, printing with movable type—a mere enumeration of inventions of this kind makes it obvious that economic revolutions were taking place. But philosophy in the Greek sense and scientific research in the modern sense were completely lacking. Instead, we had hair-splitting commentators, astrologers and alchemists.

Alchemists as a class, like the more remote glass makers and woolen dyers, were not recruited from the superior minds of the day; but since the “science” had occult possibilities, men of talent, steeped as they were in the superstition of the day, were not wanting. And it is necessary at this point to emphasize that the majority of the alchemists were honest, God-fearing men, who hoped to arrive at a better understanding of God’s work through their experiments. But where, of course, such work is mixed up with the making of gold, it would be strange if charlatans were wanting. The bad odor with which alchemy is surrounded is due to the charlatans who were attracted to it; nevertheless, here and there, men of talent, and even of genius, practiced the art.

Among the latter was Albertus Magnus (1193-1280), a scholar renowned in philosophy, in theology

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and in alchemy. From all available data, it would seem that Magnus himself never did things in the laboratory, again testifying to the fact that it was still rare to find men of talent working over a fire; but he collected and arranged the known material and made a very honest attempt to interpret it. While a believer in the theory of transmutation, he acknowledged that no actual case of transmutation had come to his knowledge—a view which might have been expressed by a scientist of our own day. He describes the purification of gold and silver; he is aware that cinnabar is a mixture of mercury and sulphur; he states that when wine is heated an inflammable substance is evolved; and he mentions many metals, minerals and salts. In actual knowledge, there is not much more in Magnus's books than might be found in the Leyden Papyrus, though his works show him to be less of the cookbook writer and more one who is approaching the stage of the philosophical interpreter.

The standing of Magnus in the world of scholarship attracted much attention to what he had to say, and in this sense his service to chemistry was considerable. But a contemporary of his, Roger Bacon

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(1214-1292?), was destined, ultimately, to exert an even greater influence; not because he was a better chemist (or rather alchemist), but because he was the first clearly to grasp the importance of the experimental method as such, irrespective of any particular science or subject.

Bacon classifies the sciences into perspective (optics), astronomy, the science of weights, alchemy, agriculture, medicine and experimental science. This is a peculiar classification judged in the light of what we know to-day; but the classification is remarkable in that it sets aside experimental science as a separate branch of study. One must here carefully distinguish "experimental science," which illustrates the method employed, from "experiments," which are concrete examples of observations made. Experiments were no new things in Bacon's day or even in days much before Bacon. In fact, man had always experimented, man had always made observations, but, so far as we can discover, no one before Bacon recognized that there is some common denominator which runs through all experiments; and this we call the "experimental method" or the "scientific method." Bacon is known to the masses as the

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man who invented gunpowder, though the more carefully the matter is investigated the graver become our doubts; but to him belongs the far greater honor of "abstracting the method of experiment from the concrete problem and of observing its bearing and importance as a universal method of research."

Having studied and taught at Oxford and Paris, and having mastered the theology and the science of the day, Bacon wrote on both these subjects, applying his knowledge of books and his imagination to science as he did to theology, but no more. We have no evidence that he himself actually performed experiments; in any case, his written work is a transcript and an interpretation of "authorities"—"authorities" in science as well as in theology; and in this respect he shows no advance over Albertus Magnus. His attack on the corrupt practices of the clergy, coupled with his interest in alchemistic, and therefore "magic," work, finally cost him his liberty, and he seems to have spent the last thirteen years of his life in prison.

CHAPTER IV

PARACELSUS AND THE RELATION OF CHEMISTRY TO MEDICINE

THEOPHRASTUS BOMBASTUS VON HOHENHEIM (1493-1541), more commonly known as Paracelsus, was born one year after the discovery of America and died two years before the appearance of the immortal work on anatomy by Vesalius and the even more renowned work on astronomy by Copernicus. Dr. Singer, the medical historian, says: "If we have to name a year for the end point of medieval science we would select 1543, when appeared two fundamental modern works based on the experimental method, the *De Fabrica Corporis Humani* of the Belgian, Andreas Vesalius, and the *De Revolutionibus Orbium Caelestium* of the Pole, Nicholas Copernicus."

Perhaps at this stage, since we are dealing primarily with the development of chemistry, should be added another work, the *De Re Metallica* of Agricola, published some years later, and dealing with

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mining, geology, engineering and chemistry—a work of far-reaching importance in the development of industrial chemistry. Recently the book has become available to English readers through a translation which we owe to President and Mrs. Herbert Hoover.

Paracelsus shares honors with Roger Bacon in ushering in the experimental or modern period in science; not that Paracelsus, any more than Bacon, performed experiments, but because he, like his forerunner, urged the importance of the experimental method. Being a physician as well as a chemist, he saw very clearly how intimately connected the sciences of medicine and chemistry are, and how advances in the latter would inevitably react upon the development of the former. "When the physician," he writes, "is not skilled and experienced to the highest and greatest degree in this foundation [alchemy] all his art is in vain." And again: "For in experiments neither theory nor other arguments are applicable, but they are to be considered as their own expressions"; which could hardly be said better in our own day.

This strange man, this Bombastus (whence, so

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tradition has it, the word "bombastic" in English), lived at a time when men's minds began to open to doubt, and, among the rebels and the fighters who shouted and fought for the new and the untried, Paracelsus was in the forefront.

For consider what was going on. The universities, which had been founded in the twelfth and thirteenth centuries, were growing and multiplying and planting the roots of the spirit of independent research. Printing by movable type had come into use, and many men for the first time had access to books embodying the best thought of all time. While the immediate effect of the Reformation upon civilization was probably bad rather than good, sooner or later this movement also helped men to throw off chains of authority and foster a spirit of free inquiry. And the various voyages of discovery, such as those of Columbus to America, Vasco da Gama to India and Magellan around the earth, brought East and West into close contact and gave Europeans many new things to think about.

Into this world came Paracelsus, a rebel already in his swaddling clothes, if accounts are to be believed. He grew up in a Swiss mining region, watched his

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father practice medicine and picked up bits of knowledge about mining and mining chemistry. Details about his personal life are scarce and confusing. We are not certain where he studied, how much he studied and just what he studied. Presumably he must have taken some course in medicine, because when he was twenty-one he joined the Danish army as a physician and he seems to have remained in active service—in Denmark and elsewhere—for seven years.

We next find him in Basel practicing medicine and having some sort of connection with the university there. His stay here lasted scarcely a year. Just what happened is not altogether clear, but the evidence points to violent disputes between the established medical fraternity, who were obedient followers of Galen, and Paracelsus, who was opposed to Galen and all Galen's followers. To the professors, medicine was static and complete, like religion, and Galen was the god; to Paracelsus, medicine was one of a number of sciences which could expand and grow with the continuous application of the experimental method. Obviously, there could be no compromise between the two camps; and since the professors were

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established and in authority, Paracelsus was forced to leave Basel in somewhat of a hurry.

From now on he became a wanderer. The professors were everywhere in arms against him. He preached a new "religion" in medicine; he was a dangerous "radical," disobeying and teaching others to disobey. Teaching others to disobey was the bigger sin. He sought for truth in nature, not like that other great martyr, Socrates, by a constant searching of the soul, but by an appeal to experiment. It must, however, be emphasized again that Paracelsus was no experimenter himself, or if he was, the work accomplished must have been quite negligible. He, like Roger Bacon, merely preached the gospel of the experimental method—a method put into practice in chemistry some years later by Boyle and others.

His writings, his preachings and his combative spirit made Paracelsus many enemies but also some friends and enthusiastic followers. The friends and followers grew to enormous proportions after his death (which occurred in Saltzburg, when he was forty-eight years old), and the name of Paracelsus threatened for a time to become as sacred as that of Galen had been, giving occasion to the fear that chem-

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istry might again become a static subject. His vogue for a time was so great that his adoption of the Greek-Arabian view that metals had their origin in sulphur, mercury and salt, which, in turn, were the primary products of earth, air, fire and water, was enough to make it the prevailing view for many years, until the conception of phlogiston (about which we shall have something to say presently) caught the public fancy.

Paracelsus never quite gave up some of the more fantastic and mystical phases of the art of the alchemist, and in this sense he was true to his times. But he was also a Moses with a vision to see the promised land and to appreciate its boundless possibilities.

CHAPTER V

ROBERT BOYLE AND THE CONCEPTION OF AN ELEMENT

THE period bridging the gap from Paracelsus (1493-1541) to Robert Boyle (1626-1691), the latter among the first of rational chemical experimentalists in the present-day sense, is a period which witnessed a rapid intellectual awakening. Guided by the bankers and merchants of Venice and Genoa and later by those of Amsterdam, intercontinental trade was largely extended. Side by side with a flourishing commerce, Italian art, reaching its apex in Michelangelo and Raphael, continued active, if somewhat more imitative in the later stages of the period. The possibilities of architecture were summed up, in a sense, in the construction of St. Peter's Church in Rome, the great dome of which owes its existence to Michelangelo. Music, in the earlier years, was largely a handmaid of religion; and the compositions of various masters, particularly Palestrina, did much to beautify the Roman Catholic ser-

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vices. In time the Italians turned their attention to grand opera which, however, did not reach any very great heights until well within more contemporary times.

Spain and Portugal, for a time among the most powerful nations in Europe, rich in treasures derived from Mexico, Peru and the East Indies, followed in the wake of Rome and declined rapidly as its nobles became more corrupt and pleasure-seeking, and as its officials continued to persecute both the Moors and the Jews, to whom much of the commerce and industrial enterprise of the nation was due. It was during this period, however, that Cervantes wrote his immortal *Don Quixote*, and that El Greco, Murillo and the incomparable Velasquez adorned Spanish art.

The Dutch Republic, successful in its struggle against Spain, blossomed into a strong maritime power, though England and France did much to hamper this expansion. Rubens, Van Dyck and, above all, Rembrandt developed the Dutch school of painting equal to the best of the world's production. Here the gentle and profound Spinoza, the "god-intoxicated man," as he has been called by one

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admirer, polished lenses and wrote learned treatises. Here the persecuted from all countries found a haven of refuge.

Across the channel, in England, the ruthless Henry VIII and his worthy daughter, Elizabeth, ruled over a country which rapidly came into its own, only to degenerate again under the Stuarts. During the Elizabethan period, Bacon, Spenser, Marlowe, Ben Jonson and the master of them all, Shakespeare, lived and wrote.

The later stages of this period were more or less dominated by Le Grand Monarque, Louis XIV of France, and all that he stood for. The influence of France, in which was to be found a certain culture and breeding, if also mixed with much that was pompous and artificial, extended throughout Europe—to England, to Germany and even to Russia. Despite a rather empty and showy period in art, enlivened somewhat by Poussin and Claude Lorrain, French drama, in the persons of Corneille, Racine and Molière, and French literature in the persons of La Rochefoucauld, Boileau, La Fontaine and Bossuet, were of a very high order of merit.

During all this period science was making great

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strides, but not, at first, in chemistry. Copernicus vigorously attacked the old Ptolemaic theory that the earth was the center of the universe, and developed his own theory that the earth, with other planets, moved about the sun—a view which man's vanity prevented him from readily accepting. So, at least, the great Galileo, master of mechanics and astronomy, discovered to his cost when the Inquisition decided to prosecute him for his belief in the Copernican theory—a belief strengthened by his own researches and by those of Kepler, who announced the laws of planetary motion.

A contemporary, wiser than the members of the Inquisition, wrote at the time, "God and Nature have joined hands and created the intellect of Galileo." Keeping in mind this simile, we can also say, "And God said, let there be light"—and Newton came. The mathematical formulation of the bodies of the cosmos in terms of motion and matter and the formulation of the law of gravitation, swept away not only the last remains of astrology (and, indirectly, much of alchemy), but made possible the ever-growing conception that fixed laws, rather than supernatural outbursts, rule much on this planet.

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Just as Galileo and the astronomers did much to conquer the vastness of space with the help of the telescope, Van Leeuwenhoek and others, using the microscope, uncovered an equally vast domain in the world approaching the infinitesimal. Protozoa and bacteria now first came to light. And in the related fields of anatomy and physiology, Vesalius and Harvey announced discoveries of great importance dealing with the structure and function of living bodies.

Side by side with discoveries due to individual genius, learned academies were established in Italy and in Paris, and the Royal Society was founded in London. These learned bodies served two purposes, both of which had the effect of accelerating progress in science: they brought men of science together at frequent intervals, when demonstrations, discussions and frank criticisms acted as stimulants to further thought and further experimentation; and the learned men very soon decided to establish the "proceedings" of the academy or society, in which accounts of papers presented by members were printed. By this means, a rapid international exchange of scientific opinion first became possible.

Representing roughly a period of 200 years—

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from about 1500 to 1700—the intellectual development in Europe which we have so briefly sketched, and more particularly the epoch-making work of scientists of the type of Newton and Galileo, could not but have a profound effect upon the science of chemistry. So far we have witnessed men who preached but did not practice. Even Paracelsus, one of the last of the race, who wrote volumes, does not seem to have worked in the laboratory. He certainly made no discovery resulting from experimental work. But the chemists received a stimulus from the experimental work being done in the related field of physics; and this is strikingly seen in the work of Van Helmont (1577-1644), a prominent chemist of his time who, though in many ways an ardent admirer and follower of Paracelsus, and even a believer in the transmutation of base metals into gold, developed his own theories, but these were based upon experiments.

A favorite theory of his was that the two primary bodies were air and water. All things originated from air and water. This was an attempt to do away with the four elements of Aristotle and the three principles of Paracelsus; but his criticism of

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these two men was founded upon experiments which were done with care, though they were completely misinterpreted.

To show that water was one of the primary forms of matter, Van Helmont put a five-pound willow in an earthenware pot containing 200 pounds of dried earth. He watered the pot constantly for five years, but aside from water, the willow received nothing. At the end of this time the willow was found to weigh somewhat over 169 pounds, whereas the earth had lost but two ounces. Where did the new willow material come from? From the water, said Van Helmont. Hence, water is one of the primary forms of matter. Of course, had he been familiar with plant respiration and plant metabolism, he would have known that the plant takes in considerable quantities of carbon dioxide from the air and that the whole process of photosynthesis is very far from being the simple affair he thought it was. But of primary interest to us is that Van Helmont appealed to experiments in support of his theory. This was an important step in advance.

Van Helmont, as we have seen, still believed in the

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transmutation of base metals into gold. He remained sufficient of a follower of Paracelsus to regard chemistry merely as a handmaiden of medicine. But in Robert Boyle (1626-1691), the outstanding chemist of the period, we find an attitude towards chemistry which, in most respects, is thoroughly modern. To begin with, chemistry was to him a very distinct branch of knowledge, worthy of pursuit for its own sake. He may truly be regarded as the first "chemist" in the sense in which we use the word to-day. He was even more insistent than was Van Helmont on the importance of experiments; and he was forever experimenting. If some of the misleading doctrines of the time received his support, it is to his eternal credit that he disregarded the Aristotle-Paracelsus-Van Helmont ideas of primary substances, and gave us a definition of an element which has stood the test of time, to be modified only recently as a result of radioactive studies. "I mean by Elements," he writes in his *Sceptical Chymist*, "certain Primitive and Simple, or perfectly unmingled bodies; which not being made of any other bodies, or of one another, are the Ingredients of which all those called

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perfectly mixed Bodies are immediately compounded, and into which they are ultimately resolved." The confused ideas regarding the nature of burning (about which we shall have something to say in the next chapter) prevented Boyle from recognizing that many such elements existed in nature. That the metals are elements he did not know.

Being a son of the Earl of Cork, who was Lord High Treasurer of Ireland, Boyle's experiments and writings were more quickly noticed than they otherwise would have been; and the science of chemistry was fortunately the gainer thereby. He was one of the founders of the Royal Society and was for a number of years its president. In his case, his studies at Eton, Geneva and Florence did more than merely fit him to be a gentleman. Even while a student in Florence, studying languages, modern history, fencing and dancing, he records that "the new paradoxes of the great stargazer Galileo, whose ingenious books, perhaps because they could not be so otherwise, were confuted by a decree from Rome."

A pioneer chemist—he discovered, among other things, wood alcohol, phosphoric acid and the darkening of silver salts by light (which is the basis of

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photography)—Boyle is best remembered as the author of the law which bears his name and which states that the volume of a gas varies inversely with the pressure—one of a number of laws with which the beginner in physics is plagued!

CHAPTER VI

THE PHLOGISTON THEORY

THIS chapter as well as the two succeeding chapters follow one another very closely in terms of years. The period covered is approximately one hundred years—from about 1700 to 1800—and both Priestley and Lavoisier, who are treated in the next two chapters, lived and worked during this time.

In the history of chemistry, the early years of this century are noteworthy in the attempt made to formulate the first comprehensive theory, a theory upon which many chemical reactions were built. That this “phlogiston” theory eventually proved to be the reverse of the truth is a matter of great regret, for it retarded much progress in the science; but it caught the imagination of men and stimulated them to further efforts in experimental work. In this sense the phlogiston theory—the word “phlogiston” comes from a Greek word meaning “flame”—did yeoman service for the cause.

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Now what are some of the essential features underlying this theory which was first clearly enunciated by Stahl (1666-1734), a German chemist, and which was accepted by the foremost chemists of the time, such as Black, Cavendish, Priestley and Scheele?

The theory, to begin with, dealt with the nature of combustion—the nature of burning. Fire and heat, in a sense, represent the tools of the chemist. Most of his reactions need them. It is not surprising, then, that from the earliest times men should have wondered about the nature of combustion. Stahl supplied the world with an answer which satisfied for a time. Substances which burn readily contain much of the mysterious phlogiston; substances which do not burn readily contain less of it. When a substance burns it loses this mysterious “something,” this phlogiston.

Had the balance been a more common piece of apparatus in the laboratory of chemists, this theory would hardly have seen the light. For obviously when a substance loses something it ought to *lose weight*; but as a matter of fact, when a substance burns, it *gains* weight. When a piece of paper is

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burned, the ash *plus* the other products which go off as gases weigh more than the original paper. This applies to every case of burning; no exception to the rule is known.

That substances increase in weight on burning was not altogether unknown to Stahl and his followers; but since phlogiston was something in the nature of a "spirit," the laws of matter hardly applied to it; and some even suggested that it had negative weight!

We shall see presently that oxygen, a constituent of the air, plays an indispensable part in all cases of combustion. But so blindly do we often follow a theory, that even Priestley himself, who discovered oxygen, believed and fought for the phlogiston theory until the day of his death!

Stahl, like Paracelsus, was a physician by training, but taught medicine and chemistry at the University of Halle for many years. Then he was called to Berlin as Royal Court Physician and here he continued practicing and preaching and enlarging his school of admirers.

CHAPTER VII

PRIESTLEY AND OXYGEN

WE are now well on the way to sound experimental work. Though dominated by the principle of phlogiston, men were actively exploring. And more particularly were they intrigued with "airs" and "gases" of all kinds. The properties of substances which, as a rule, can neither be seen nor felt seem at first sight to be the properties of beings not of this earth; and possibly the original approach to a study of gases was via the road of the mystic.

Still, when we come to record actual discoveries of gases, all signs of mysticism have completely disappeared and we are face to face with men of little less critical acumen than the scientists of our day. Joseph Black (1728-1799), for example, who held the chair of chemistry at Edinburgh, has left us a record of his "fixed air" experiments which may well serve as a model for the research students of our day. Black's "fixed air" is none other than carbon dioxide, a gas which we continually exhale. He obtained

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it in ways which are now commonly employed in the laboratory, such as by burning charcoal and by the action of acids on limestone; and being a devoted follower of Stahl, he developed the idea that fixed air was a strange combination of the ordinary air with phlogiston. However, we must do Black justice to record that eight years before his death, in a letter to the French chemist, Lavoisier, he decided against phlogiston and in favor of the newer and radical theories of the French savant.

Henry Cavendish (1731-1810), an eccentric English aristocrat, was another active "gas" worker; and to him is credited the discovery of "inflammable air" or, as it is known to-day, hydrogen. But by far the most important of these "gas" discoveries is due to Priestley and to Scheele, both of whom, quite independently, discovered oxygen.

Scheele (1742-1786), a Swedish apothecary all his life, was a rare genius. He uncovered new elements such as chlorine and manganese, new compounds such as tartaric, uric and prussic acids, and greatly improved the methods of chemical analysis. If Priestley is usually credited with the discovery of oxygen, it

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is because Scheele published his discovery some years after the English chemist.

Joseph Priestley (1733-1804) was really a very remarkable man, aside from being a very brilliant chemist. He was somewhat of a minister, somewhat of a classicist, somewhat of a political writer, and very much of a scientist. In his earlier years he was a teacher at an academy in England, where his specialties seem to have been the classical languages and "polite" literature. He also wrote books on education, on history in general and the history of England in particular, on the constitution and laws of England, on biography and on electricity; which would imply that he wrote too much and on too many subjects to write particularly well on any one subject. And as a matter of fact, these books, viewed in the most favorable light, were little more than compilations.

In his next position, as minister of a chapel in Leeds, he continued to write—on perspective, and on vision, light and colors; but he also began to experiment with the "fixed air" which came off in such quantities from a brewery near by. He conceived the

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idea that—to use the words of the then president of the Royal Society—“common water impregnated with this fluid (that is to say, carbon dioxide) alone might be useful in medicine, particularly for sailors on long voyages, for curing or preventing the sea scurvy.” Sea scurvy can hardly be cured with Seltzer water but Priestley was awarded the Copley Medal for this work.

Then came an offer, in 1772, of a position as librarian to Lord Shelbourne, a position which meant little work and much leisure; and of this leisure Priestley made much use. It was in 1774 that he made his most celebrated discovery, that of oxygen. With the help of a powerful lens he heated various substances to see what kind of “air” could be expelled from them. One of these substances was mercuric oxide. The “air” it yielded on heating was carefully collected and its properties examined. “But what surprised me more than I can well express was that a candle burned in this air with a remarkably vigorous flame.”

Not so very long after this discovery, Priestley accompanied Lord Shelbourne to Paris and there met Lavoisier. Lavoisier, as we shall see presently, was

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actively at work developing his great theory of combustion, and, as in this theory oxygen plays a very important rôle, it can well be imagined with what interest the Frenchman heard of the Englishman's discoveries. Of this there is no doubt: that Priestley discovered oxygen; but that Lavoisier and not Priestley grasped the full significance of the discovery. Priestley returned as firm a phlogistonite as ever, and to phlogiston he was faithful unto the end.

In the meantime, with very heterodox views on politics, on education and on religion, his association with Lord Shelbourne became more and more unpleasant. The noble lord was a scholarly but conservative gentleman. His lordship admired Priestley's chemical discoveries but very much disapproved of everything else in Priestley. Priestley now decided to sever this connection with Shelbourne, and once again he became a minister—this time of a dissenting congregation in Birmingham.

He now wrote a book on the corruptions of Christianity which brought him into trouble with the ecclesiastical authorities. He next preached and wrote in favor of the American and French revolutions; and this brought him into trouble with the govern-

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mental authorities. On July 14, 1791, a group of sympathizers in Birmingham celebrated the fall of the Bastille. As the English government had no sympathy for the French revolutionists, it took good care to present the French people in the worst light possible. The mob, as usual, followed the rulers blindly. Hearing of the Birmingham celebration, a mob marched to the chapel where Priestley preached, burned it, and then proceeded to burn his residence and laboratory.

Priestley escaped to London. Here he found little sympathy. Edmund Burke attacked him in the House of Commons, the press assailed him, and, be it added with much shame, his fellow members of the Royal Society were so hostile that he resigned from the body.

In 1794 Priestley emigrated to Northumberland, Pennsylvania, to join his sons who had already established themselves there. America received him with open arms; and the last ten years of his life—he died in Northumberland in 1804—were probably his happiest.

CHAPTER VIII

LAVOISIER AND THE INTRODUCTION OF QUANTITATIVE IDEAS

THE revolution in chemistry which was to convert it into the science which we know to-day had its analogue in revolutions of another character. America freed itself; and the French proclaimed to the world that a new order of things had come into being. What with shameless corruption and extravagance in the highest quarters; what with extreme misery in the lowest; what with such pens as Voltaire's and Rousseau's inciting to rebellion, a violent storm might have been foretold. But for some years before the storm broke out, such benevolent despots as Frederick the Great of Prussia, Joseph II of Austria and Catherine of Russia, following loyally in the wake of Louis XIV, strove desperately to give meaning to the word "imperial," governed in some ways not unwisely, and above all encouraged the arts. It was an age of Lessing, Schiller and Goethe in literature; of Bach, Mozart and Beethoven in music;

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of Reynolds, Romney and Gainsborough in painting. It was an age of scholars and philosophers such as Adam Smith and Gibbon and Kant and Diderot and D'Alembert, together with the entire school of French encyclopedists. It was the age in which America gave to the world one of its most interesting and talented personalities, Benjamin Franklin.

But far more significant for the future was the economic revolution which had set in. For many centuries the daily life of the people had changed very little. It has been said that "the Saxon farmer of the eighth century enjoyed most of the comforts known to the Saxon farmers of the eighteenth century." But in the eighteenth century things began to change. The age of machinery, of invention, of applied science had set in—to culminate in our own day in material luxuries which were undreamed of fifty years ago, and in the butchery of the Great War.

The inventions and applications did not come suddenly and overwhelmingly, even though the eighteenth century is considered as the turning point in our history. Some noteworthy inventions and discoveries had already been in use for some time. There were, for instance, the printing press, and the

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clock, and the stocking-knitting frame and the multiple plough; and early in 1600 the suggestion was made to use coal in the place of charcoal for the manufacture of iron, a suggestion which was not put into effect until much later because the charcoal burners were violently opposed to the reform. In agriculture many innovations were introduced. Seeds and soil were studied; the Dutch originated the rotation of crops; the value of fertilizers, of irrigation and of drainage gradually came to be appreciated. In the field of textiles, inventions came later. Arkwright's spinning jenny, the result of much labor by many men, came comparatively late. This was followed by the invention of the power-loom by Cartwright and of the cotton gin by Whitney. The "factory" system had started.

The factory calls for machinery, and machinery calls for power and power means coal. The digging of coal in England (where the factory system first took root) spread to other countries; and with the production of coal in quantity came the manufacture of iron and steel in corresponding amounts; particularly so after the invention of Watt's steam engine, Fulton's steamboat and Stephenson's locomotive.

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Rubber was known to Priestley, who used it as an eraser, but its enormous potentialities loomed into view much later, when Goodyear devised his process of vulcanization. The age of petroleum had not yet set in.

If we turn our attention more specifically to industrial chemistry, an outstanding event is the discovery, in 1746, of the "chamber" process for making sulphuric acid (or oil of vitriol). Sulphuric acid has been appropriately called the most important single chemical known to man, since the manufacture of ever so many other substances is dependent upon its use. It is, perhaps, no exaggeration to date the rapid growth of applied or industrial chemistry to the large-scale production of this acid.

But we must also mention one or two other discoveries of importance in industrial chemistry. In these years coke and even coal gas were made from coal, though their applications in iron manufacture and in lighting, respectively, came later. Le Blanc devised his method of making washing soda, which is among alkalis what sulphuric acid is among acids, and Achard, applying Margraf's discovery, prepared beet sugar in large quantities.

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Side by side with the industrial revolution, a much quieter revolution was taking place in science in general and chemistry in particular. Discoveries were being rapidly multiplied in every direction, and the first necessity was a more rigorous classification, not only among the sciences but within each science. Under the patient eye of Linnæus, "systematic" botany came into being; and through the influence of several workers, branches of medicine, such as histology and pathology, emerged. The idea of "quantity," which had long been applied in mathematics and more recently in physics, now found its way into chemistry, thanks to the labors of Lavoisier. Since the idea of quantity is so intimately associated with the establishment of an exact science, the French seem justified in claiming for Lavoisier the title of "Father of Modern Chemistry."

Consider for a moment what Lavoisier accomplished. We have already emphasized the intimate association between chemical reactions and "heat" and "burning." It is, therefore, not surprising that the nature of "burning," or "combustion," should have engaged the attention of chemists even at an early stage in the development of the science. The

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speculations and experiments culminated in the phlogiston theory to which reference has already been made. Substances burn, said the phlogistonites, because they contain the mysterious phlogiston. When they burn they lose this phlogiston. Now by means of quantitative experiments, in which metals were weighed before and after heating (or burning), Lavoisier showed that metals when heated *gained* weight. One might have supposed that by losing phlogiston they would have *lost* weight. But nothing of the kind: in every instance of combustion the substance increased in weight.

Lavoisier next showed that the increase in weight is due to the combination of the substance with the oxygen of the air, that what the air lost the substance gained. Combustion, as Lavoisier pointed out, is the combination of the burning substance with the oxygen of the air, giving out heat and light.

Notice how with the very oxygen which Priestley had discovered Lavoisier overthrew Priestley's pet theory of phlogiston—a theory which the Englishman never renounced, even though data were constantly accumulating in support of Lavoisier's hy-

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pothesis. Notice, furthermore, that Lavoisier's theory of combustion rests not only upon experiments, but upon *quantitative* experiments: he had to *weigh* substances before and after burning to notice the differences in weight; he had to *measure* the volume of air before and after burning to notice whether any part of the air had disappeared.

With extraordinary insight Lavoisier applied his theory of combustion to the entire process of respiration within our bodies and showed quite clearly how our foods are "burned" in the body in the presence of the oxygen we get from the air, to yield moisture and carbon dioxide—the latter a gas which he showed to consist of carbon and oxygen in fixed proportions. Lavoisier is not only the father of modern chemistry, but he must also be regarded as the father of modern nutrition.

I write these pages in a house situated near the rue Berthollet, the rue Gay-Lussac and the rue Claude Bernard—three names treasured by chemists and physiologists. I mention this merely to show that the French, even more than other nations, are proud of their great scientists. Yet there was the period in

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French history when the master of them all (with the probable exception of Pasteur) was crucified by his countrymen.

Lavoisier (1743-1794), a Parisian by birth and by training, drifted into science quite early in his life; and as his family was comfortably situated, he had no difficulty in developing his tastes. We find him presenting his first paper to the Academy of Sciences when he was but twenty-two; and in the same year the king bestows a gold medal on him for an essay on lighting city streets. Three years later he is already a full-fledged member of that immortal Academy; and as if to make a secure financial position securer still, he becomes associated with a corporation which had the pleasant task of collecting various taxes from the people, and which added some 100,000 francs a year to Lavoisier's income. There is no reason to suspect Lavoisier of shady dealings in this connection, but there is reason to suspect other members of the firm. And in any case, we are approaching the revolutionary period when a gentleman was in danger, when a rich man was in danger, when certainly a tax collector was in danger; and Lavoisier was a gentleman, a rich man and a tax collector.

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In the meantime, in 1771, he married a young girl of fourteen whose father was also a member of the tax corporation, and who brought him a dowry to swell the already considerable fortune which Lavoisier possessed. But while he lived like an aristocrat, Lavoisier spent a considerable part of his income on his experiments and in furthering the development of the French Academy in which he always took an active interest.

In 1794, at the height of the revolution, the members of the tax corporation were arrested. Innocence or guilt mattered little; the sentence could have been foretold. Lavoisier followed his father-in-law to the scaffold. "It took but a moment to knock off that head," wrote one French scientist; "centuries will not produce such another man."

True to form, the mob, which kills one day and worships the next, in a fit of repentance twelve months later, unveiled a bust to the immortal man with the inscription:

*"Victime de la tyrannie,
Ami des arts tant respecté
Il vit toujours par le génie
Et sert encore l'humanité."*

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"I have achieved," writes Lavoisier in his last letter, "a passably long career, and a very happy one, and I believe that my memory will be accompanied with some regrets, perhaps with some glory. What more could I desire?"

CHAPTER IX

DALTON AND THE ATOMIC THEORY

LAVOISIER had introduced the balance into chemistry, and chemistry became a science. Substances were now being analyzed not only qualitatively but quantitatively, and the results of many such quantitative determinations led to a generalization known as the *law of definite proportions*.

In any one compound, the chemist discovered, we always find the same elements in the same proportions by weight. Common salt, which the chemist calls sodium chloride, when analyzed, is found to contain sodium chloride in the proportion of 23 parts by weight of sodium to $35\frac{1}{2}$ parts by weight of chlorine. It does not matter in the least what the source of the sodium chloride is. You can obtain it from sea water or you can get it from a salt mine or you can make it in the laboratory. All that matters is that the substance be chemically pure. If it is, and if it is analyzed, it will always be found to consist of sodium

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and chlorine in the proportions of 23 parts by weight of sodium to $35\frac{1}{2}$ parts by weight of chlorine.

This illustration of the law of definite proportions which we have just given holds true for every one of the thousands of compounds known to the chemist; every one of these compounds, when analyzed, is found to consist of certain elements in definite proportions by weight.

This puzzled the scientist and the philosopher. Nature uses no balance in forming its compounds, and yet the composition of Nature's compounds is such as to make one believe that Nature is the best of quantitative chemists. The puzzle was satisfactorily cleared up by John Dalton, of Manchester, a private tutor who dabbled in meteorology, and who was gradually led to a far-reaching hypothesis.

Let us suppose, said Dalton, that matter is made up of indestructible pieces very minute in size, which we shall call atoms. Let us suppose, further, that one difference between the atoms of one element and those of another is a difference in density. If, now, we arbitrarily give the relative weight number of 23 to the atom of sodium, we may assume, said Dalton, that the atom of chlorine will be $35\frac{1}{2}$. When, then,

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sodium and chlorine come together to form sodium chloride (salt), since the smallest units that can combine are the atoms, and since one atom of sodium relative to one atom of chlorine is as 23 is to $35\frac{1}{2}$, the combination must remain in the ratio of 23 : $35\frac{1}{2}$ no matter how many thousands or millions of sodium and chlorine atoms come together.

The idea of an atomos, or atom, Dalton borrowed from Greek philosophy, but its application to the problems of modern chemistry is entirely his own; and while the hypothesis received no little opposition in Dalton's day, the atomic theory, as outlined by him, stands on firmer ground to-day than ever before.

John Dalton, who was born in 1776 and died in 1844, has left us a short autobiographical note which is worth quoting. It was written twelve years before his death, at a time when honors were falling thick his way:

"The writer of this was born at the village of Eaglesfield, in Cumberland. Attended the village schools there and in the neighborhood, till eleven years of age, at which period he had gone through a course of mensuration, surveying, navigation, etc.,

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began at about twelve years to teach the village school and continued it about two years; afterwards was occasionally employed in husbandry for a year or more; removed to Kendall at fifteen years of age as assistant in a boarding school; remained in that capacity for three or four years, then undertook the same school as principal and continued it for eight years; whilst at Kendall employed his leisure in studying Latin, Greek, French and the mathematics, with natural philosophy; removed thence to Manchester in 1793 as tutor in mathematics and natural philosophy in the New College; was six years in that engagement and after was employed as private and public teacher of mathematics and chemistry in Manchester, but occasionally by invitation in London, Edinburgh, Glasgow, Birmingham and Leeds."

Not a very exciting life, you will say. No; and from all we can gather, it is not mere modesty which prevents Dalton from recording more exciting events. Being an Englishman and not a German, he cannot even tell us that some university offered him a professorship. It is true that for a time he taught at New College, in Manchester, which later was to transfer its activities to Oxford; but even here he remained

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for a comparatively short time and went back to his private tutoring, teaching youngsters all kinds of subjects for a mere shilling or two a lesson.

He remained a private tutor pretty much to the end of his day, though a pension from the state, as a reward for his scientific achievements, made life more livable. From time to time he would journey down to London to deliver a lecture at the Royal Institution (incidentally, Dalton was a notoriously poor lecturer); or make meteorological observations; or discuss ethics with his Quaker friends; or write on the subject of color blindness from which he suffered; or perform various experiments in physics and chemistry (though Dalton was a very poor experimenter). One of the brightest spots in this schoolmaster's life occurred in 1822, some seven years after the famous battle of Waterloo, when Dalton set out for Paris to pay his French colleagues a visit. That such luminaries as Gay-Lussac, Ampère, Berthollet, Laplace and Biot received him with open arms and proclaimed him a master scientist, somewhat repaid Dalton for the many years he had to wait before his theory was accepted by his fellow scientists.

As a matter of fact, the atomic theory would have

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remained in the discard for many more years but for the labors of a number of chemists, particularly Berzelius (1779-1848), the prince among Swedish chemists. This Berzelius was a remarkable analytical chemist and his quantitative investigations helped to strengthen Dalton's point of view. In our day, when millions are spent upon laboratories and laboratory equipment, it is of interest to learn the kind of laboratory Berzelius worked in—this same Berzelius whose experimental researches attracted students from the four quarters of the globe. Wöhler, to whom we shall refer later, was one of his students. "The laboratory," writes Wöhler, "consisted of two ordinary chambers with the simplest fittings; there was neither oven nor fume chamber, neither water nor gas supply. In one room stood two ordinary work tables; at one of these Berzelius had his working place. On the walls were several cupboards with reagents, which, however, were not provided very liberally, for when I wanted prussiate for my experiments, I had to get it from Lübeck. In the middle of the room stood the mercury trough and glass-blower's table. The washing place consisted of a stone cistern having a tap with a pot under it. In the other room were the

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balances and other instruments. In the kitchen, where the food was prepared by the severe old Anna, cook and factotum of the master who was still a bachelor, stood a small furnace and the ever-heated sandbath."

Amid such surroundings the quantitative method in chemistry, founded by Lavoisier, was continued and expanded by Berzelius, through whom and through whose pupils it was in turn carried to various European centers.

CHAPTER X

AVOGADRO AND ATOMS AND MOLECULES

DALTON'S atomic theory paved the way for many rapid advances in the science of chemistry. However, the time came again when confusion spread throughout the ranks of workers. This confusion resulted from the rather vague ideas people had of atoms and molecules. Neither was the conception of atomic weight at all clear; and without it, the next advance, to be discussed in the next chapter, would have been quite impossible.

An atom, we say, is the smallest particle that can take part in a chemical change, without itself being broken up. It is the unit in chemistry. It is the smallest unit which takes an active part in chemical changes, though it is by no means the smallest piece of matter known. On the other hand, a molecule is the smallest particle of matter which still retains the properties of such matter. It consists of two or more atoms.

Let us illustrate. Hydrogen is a colorless, tasteless,

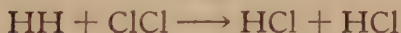
AVOGADRO

odorless gas and very inflammable. The smallest particle of hydrogen which retains these properties is a molecule of hydrogen, H_2 , which is made up of two atoms of hydrogen, $H + H$. Chlorine is a gas with color and odor. The smallest particle of chlorine which retains these properties is a molecule of chlorine, Cl_2 , made up of two atoms of chlorine, $Cl + Cl$. Now when one volume of hydrogen is mixed with an equal volume of chlorine and the mixture sparked, the two gases unite to form two volumes of hydrogen chloride.

The reaction may be represented as:



or



You will notice that whereas H_2 (the molecule) or Cl_2 (the molecule) is found only on the left-hand side of the equation, H (the atom) and Cl (the atom) are found on both sides of the equation. The atom may change hands, but is not decomposed. The molecule, however, may be decomposed into atoms.

We have assumed the molecule to consist of at least two atoms. With the help of Gay-Lussac's observations and Avogadro's hypothesis, this assump-

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tion can be tested. Gay-Lussac found that gases combine (if they do at all) in simple ratios by volume. One volume of oxygen, for example, combines with two volumes of hydrogen; one volume of hydrogen combines with three volumes of nitrogen; one volume of hydrogen combines with one volume of chlorine. Notice the whole numbers—never one-third of a volume or one and two-thirds volumes. The ratios are always in the nature of whole numbers, 1, 2, 3, etc.

Avogadro, on the other hand, as a result of his speculations, arrived at the conclusion that equal volumes of gases contain the same numbers of molecules, provided that the temperature and pressure are the same.

Let us return to our hydrogen and chlorine:



Gay-Lussac tells us that one quart of hydrogen combines with one quart of chlorine to form two quarts of hydrogen chloride. Assume, for the sake of argument, that the one quart of hydrogen consists of one million molecules of hydrogen (actually the number is many millions more than this). Since, according to Avogadro, equal volumes of gases contain

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the same number of molecules, one quart of chlorine must also contain one million molecules of chlorine, and two quarts of hydrogen chloride must, in turn, contain two million molecules of hydrogen chloride.

Each molecule of hydrogen chloride cannot possibly contain less than one atom of hydrogen, from our very definition of an atom. Two million molecules of hydrogen chloride must contain at least two million atoms of hydrogen. But these two million atoms of hydrogen could only have come from the one million molecules of hydrogen (left-hand side of the equation), for it is inconceivable that hydrogen atoms can be derived from chlorine atoms. Hence we arrive at the conclusion that one million molecules of hydrogen give rise to two million atoms of hydrogen; or one molecule of hydrogen may give rise to two atoms of hydrogen. Similarly, it can be demonstrated that one molecule of chlorine gives rise to two atoms of chlorine.

These pretty proofs, probably reminding the reader of his Euclid, have had far-reaching effects, as subsequent chapters will attempt to show. We have now arrived at a point where a sharp distinction can be made between an atom and a molecule and where

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we can regard the atom as the unit in chemistry. Chemistry, we can say, is a reaction between atoms.

These molecules and atoms are inconceivably small. Studies in radioactivity have made it possible for us to state that there are 27,000,000,000,000,000,000 molecules of gas in one cubic centimeter, and one cubic centimeter is about one one-thousandth of one quart. It is a comparatively simple matter to weigh one cubic centimeter of gas, divide its weight by the number of molecules (the 27 with the endless zeros) and thereby obtain the weight of one molecule. By halving this figure we get the weight of one atom (if we assume two atoms to the molecule).

When, however, we speak of the atomic weight of an element—a number which will assume importance in the next chapter—we do not mean the weight of one atom of that element. The idea of atomic weight, which we owe in large measure to Cannizzaro, was advanced before we had exact methods for weighing a molecule. Speaking broadly, when we say that the atomic weight of oxygen is 16, we mean that the weight of the atom of oxygen is 16 times that of an atom of hydrogen, provided we assume

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the atom of hydrogen to be one (unity). When we say that the atomic weights of sodium and chlorine are 23 and $35\frac{1}{2}$ respectively, we mean that their atoms are 23 and $35\frac{1}{2}$ times as heavy as an atom of hydrogen. The numbers, then, are not absolute but relative.

With this necessary preamble, we shall devote some space to the men who were primarily responsible for the work and who set the stage, as it were, for the next great advance.

Gay-Lussac (1778-1850), the discoverer of the simple volume relationships among gases, worked his way from utter obscurity to a professorship at the École Polytechnique in Paris and became one of the first chemists of his time. He was a pupil and friend of Berthollet; he accompanied Humboldt on one of his European expeditions; he ascended the unheard of height (at the time) of 7,000 meters in a balloon to examine magnetic forces in space and to test the composition of the atmosphere; he did much physico-chemical work; and when he died the grateful Parisians named one of their streets after him.

Amedeo Avogadro (1776-1856), the glory of

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Italy, published his immortal theory in 1811, a theory which, with Gay-Lussac's law, gave us new conceptions of the atom and of the molecule, but he died comparatively unknown outside of his own country until Cannizzaro brought his genius to light. Avogadro studied and practiced law before he turned to mathematics and to physics. In 1820 he was appointed professor of mathematical physics in Turin, and six years before his death he retired to meditate and to write.

It remained for Cannizzaro, at one of the international chemical congresses, to proclaim to the world the genius of his neglected countryman, Avogadro, and, in turn, to expand Avogadro's hypothesis. Cannizzaro (1826-1910) was a strange combination of soldier, diplomat and chemist. In his early days he took an active part in rebellions in Sicily, and when these failed, he fled to Paris and there entered Chevreul's laboratory to study chemistry. Once again, after his return to Italy, he left his laboratory to take an active part in the Garibaldi uprising, and from then on, even though fights became rarer, he worked for the united Italy that was to be. As professor, successively, at Genoa, Palermo, and finally Rome,

AVOGADRO

he, together with his students, published many original contributions in the field of organic chemistry, but his fame rests as the expounder of Avogadro's hypothesis and as the chemist who gave his brother workers our modern conception of atomic weight.

CHAPTER XI

MENDELÉEFF AND THE PERIODIC LAW

WHAT interests us in this book are some of the significant advances made in the science of chemistry. These advances become possible when a considerable amount of data has been collected which needs classification. At such a stage there arises some genius who detects family relationships, who develops some theory which brings into the sphere of vision a mass of apparently unrelated phenomena, and who then proceeds to build upon his theory and looks into the beyond. Our interest is, of necessity, limited to the few geniuses, though we do not want to overlook the fact that it is the work of the masses (in our case, the countless research workers) which gives genius its tools.

Dalton's atomic theory and Avogadro's hypothesis were based upon hundreds and hundreds of analyses of compounds, and the next significant advance, the periodic classification of the elements, was based upon many determinations of atomic weights of the ele-

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ments and upon Cannizzaro's interpretation of the meaning of atomic weight (to which we have already alluded in the last chapter).

The chemist looks around him and he finds the external world, animate and inanimate, made up of thousands of compounds. All these substances are similar to the common salt we discussed in a previous chapter in at least this respect: that in any one of these compounds we always find the same elements in the same proportions by weight. There are compounds like carbohydrates and proteins in the plant and animal world, and compounds like limestone and iron oxide (from which iron is obtained) in the mineral world. The carbohydrate, the protein, the limestone and the iron oxide have this in common: they are made up of certain elements in fixed proportions by weight.

The elements, in turn, are substances which cannot be decomposed by the usual methods known to the chemist. Gold and copper and iron and oxygen are elements. There is no way of decomposing gold or copper or iron or oxygen into some other substances. At least, there is no chemical way of decom-

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posing them, and ways other than chemical we shall discuss later on.

It is important, at this stage, that the reader understands clearly this conception of an "element." Gold, we have said, is an element. I can cause this gold to combine with another element to form a compound; I can make gold and chlorine combine to form gold chloride, but I cannot decompose gold and I cannot decompose chlorine. Compounds can be decomposed, but elements cannot. I can decompose gold chloride into gold and chlorine, but I cannot decompose gold or chlorine into anything else.

These elements, of which there are some 92, are the bricks with which all of the external world around us is built. It is these elements, with their respective atomic weights, which received attention from Mendeléeff.

Ten years after the publication of the *Origin of Species* and one year prior to the outbreak of the Franco-Prussian war, the prelude, as it were, to the Great War—in other words, in 1869, Mendeléeff published a short note in the Russian Chemical Society's Journal entitled *On the Relationships of the Properties to the Atomic Weights of the Elements*,

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in which there occurred this sentence: "The elements, if arranged according to their atomic weights, exhibit an evident periodicity of properties." Let us see what this means.

Suppose we arrange the elements in the order of *ascending* atomic weights. For the sake of simplicity we shall confine ourselves to the first sixteen. If the numbers used represent atomic weights, then we have:

Helium	4	Lithium	6.9	Beryllium	9	Boron	10.8
Neon	20	Sodium	23	Magnesium	24	Aluminum	27
Carbon	12	Nitrogen	14	Oxygen	16	Fluorine	19
Silicon	28	Phosphorus	31	Sulphur	32	Chlorine	35.5

The chemist immediately recognizes that there are striking family resemblances between helium and neon, lithium and sodium, beryllium and magnesium, etc. In other words, if we arrange our elements in series of *eights*, in the order of increasing atomic weights, the elements in any one vertical column show similar properties. This is what Mendeléeff

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meant when he spoke of the elements showing a "periodicity" of properties.

This periodic law is really more complicated than our exposition would leave the reader to believe; but for our purpose all complications can here be discarded. For us the important lesson that the periodic law teaches is that since there are family relationships among the elements, since there are brothers and sisters, there must be fathers and mothers; from which we conclude that there must be a "something" in the universe simpler and still more fundamental than the elements—a "something" out of which the elements themselves are built.

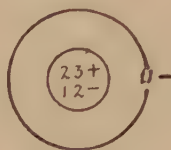
This "something," recent studies have shown, is the proton and the electron, the positive and the negative particle of electricity. All atoms are made up of protons and electrons. The atoms of any element, such as gold, are practically alike, but an atom of gold is different from an atom of chlorine. On the other hand, the protons and electrons, so far as we can tell, are the same, whether they are found in an atom of gold, in an atom of chlorine, or in any atom of the 92 elements. The protons and the elec-

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trons are obviously more fundamental units than the atoms of Dalton.

But in what way, you might ask, do the atoms differ, seeing that they are all made up of protons and electrons? The answer is in the *number* and in the *arrangement* of these protons and electrons. Here again a concrete illustration will make the point clear.

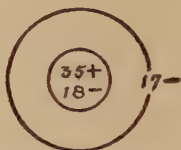
We picture the atom as a sort of solar system, in which the sun, or "nucleus," consists of protons and electrons, and the planets, or "shells," consist of electrons. The sodium atom has 23 protons and 12 electrons in the "nucleus" and 11 electrons in the "shell." In its simplest form it can be represented as



There is an excess of 11 protons in the nucleus, which, in turn, are exactly neutralized by the 11 electrons in the shell; so that the atom, as a whole, is electrically neutral. The chlorine atom has 35 pro-

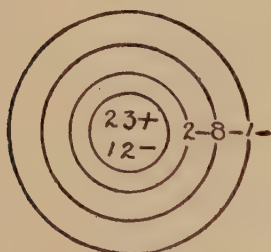
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tons and 18 electrons in the nucleus, and 17 electrons in the shell, or

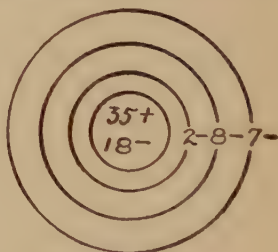


There are 17 more protons than electrons in the nucleus and these are exactly neutralized by the 17 electrons in the shell.

In the two elements under discussion, the electrons in the shell are pictured as being distributed thus:



SODIUM ATOM



CHLORINE ATOM

So that the essential difference between a chlorine atom and a sodium atom lies in the number and in the arrangement of their protons and electrons. Here again, for the sake of simplicity, all complications have been avoided.

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The $23+$ represents the *atomic weight* of the sodium atom and the $35+$ the *atomic weight* of the chlorine atom. The difference between $23+$ and $12-$, or $11+$, is known as the *atomic number* of sodium. The atomic number of chlorine would then be the difference between $35+$ and $18-$, or $17+$.

Just prior to the outbreak of the World War, these atomic numbers were determined experimentally for the various elements. If we list the elements in the ascending order of their atomic numbers (the figures representing the atomic numbers), we have hydrogen 1, helium 2, lithium 3, beryllium 4, boron 5, carbon 6, nitrogen 7, oxygen 8, fluorine 9, neon 10, and so on, until we reach the last element in the list, uranium, with an atomic number of 92. Each succeeding element increases by 1 (unity). Now this, remember, is purely the result of experiment, and this "regular flight of steps," 1, 2, 3, 4 . . . , suggests that we have unearthed a profound secret of the universe.

The English physicist, Moseley, in his early twenties, brought to light these atomic numbers. This was in 1913. Then came the World War and the expedition to Gallipoli. Moseley set out for Gallipoli and

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never returned, and another Newton and another Einstein was sacrificed.

But we must return to Mendeléeff, who laid the foundations for so much that is marvelous in modern physics and modern chemistry. He was born in 1834 and died in 1907. He was one of 14 or 15 or 16 children (authorities differ). He was brought up in Tobolsk, a town in Siberia, where his father was a teacher in the Gymnasium. His father died when Dimitri Iwanowitch (the chemist) was still a young boy, and his mother, a remarkable woman, undertook the care of her little battalion of offspring, as well as the directorship of a glass factory. Years later Mendeléeff dedicated a volume of his to the memory of his mother, and we can gather the profound influence this woman must have exerted upon her son:

“This investigation is dedicated to the memory of a mother by her youngest offspring. Conducting a factory, she could educate him only by her own work. She instructed by example, corrected with love, and in order to devote him to science she left Siberia with him, spending there her last resources and strength. When dying, she said, ‘Refrain from illu-

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sions, insist on work and not on words. Patiently search divine and scientific truth.' She understood how often dialectical methods deceive, how much there is still to be learned, and how, with the aid of science, without violence, with love but firmness, all superstition, untruth and error are removed, bringing in their stead the safety of discovered truth, freedom for further development, general welfare and inward happiness. Dimitri Mendeléeff regards as sacred a mother's dying words. October, 1887."

"With the aid of science, without violence. . . ." Significant words, these. The Russia of the eighties was the Russia of violence, the land distinguished for a few great scientists, but quite devoid of the spirit of science. As student, and later as professor at the University in St. Petersburg, Mendeléeff was a constant eye-witness of and often an unwilling participant in the squabbles between the students and the reactionary forces of the Government. Mendeléeff himself was not an extremist in either direction: neither the radicalism of the students nor the ultra-conservatism of the ruling classes appealed to him; and because of this he often found himself the target of both the camps.

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At twenty-five, after he had graduated from the University, he was allowed a government stipend which enabled him to visit and work in France and Germany. It does not seem that either in Paris or in Heidelberg did this original man work under a professor. In Heidelberg he worked on his own problem, in his own laboratory. In 1866 he was appointed to the chair of chemistry in St. Petersburg, and here he remained for the greater part of his life.

Mendeléeff arrived at his great generalization, the Periodic Law, in the course of preparing his monumental work, *The Principles of Chemistry*, which has been described as the inspiration of more Ph.D. theses in chemistry than any other published work. "The properties of the elements," he tells us in Volume II of his *Principles*, "as well as the forms and properties of their compounds, are in periodic dependence on, or (expressing ourselves algebraically) form a periodic function of, the atomic weights of the elements." Apparently because of criticism from some quarters that men other than Mendeléeff were entitled to some credit for this discovery of periodicity, he writes: "I consider it well to observe that no law of nature, however general, has been

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established all at once; its recognition has always been preceded by many presentiments. The establishment of a law, however, does not take place when the first thought of it takes form, or even when its significance is recognized, but only when it has been confirmed by the results of experiment which the man of science must consider as the only proof of the correctness of his conjectures and opinions."

A theory in science is of value in so far as it helps to explain the "facts" and in its ability to *predict*. That the periodic hypothesis explained the "facts" remarkably well no one challenged, but what added many recruits to the new theory, and what eventually established it as an accepted generalization, was the way in which Mendeléeff could predict the properties of several hitherto undiscovered elements by making use of his periodic table. When, later, three of the "unknown" elements were isolated, and their properties studied, the close agreement between the properties experimentally determined and those predicted by Mendeléeff was little short of miraculous.

"No law of nature has been established all at once," wrote Mendeléeff. He had in mind such men as the German Lothar Meyer and the Englishman

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Newlands, both of whom were struck by the possibilities of the periodicity of the elements. Newlands went so far as to read a paper on the subject before the English Chemical Society, and the frigid and even semi-mocking reception he received sent him home a sick man. But years later the Royal Society awarded him one of its medals, and the traitor of yesterday became the hero of to-morrow.

CHAPTER XII

WÖHLER AND ORGANIC CHEMISTRY

SO far we have been discussing what the chemist calls inorganic chemistry. But rather early in 1800, beginning more particularly with Liebig (1803-1873) and Wöhler (1800-1882), "organic" chemistry began to be studied. The word "organic" implies something which has to do with life; and for a long time it was supposed that organic compounds were sufficiently mysterious to prevent the chemist from manufacturing them in the laboratory. Then came the revolution in 1828, when Wöhler succeeded in synthesizing urea.

In a letter to his master, Berzelius, Wöhler writes: "While I was with you I tried to make ammonia combine with cyanic acid. I always obtained a crystalline body which gave the reactions of neither one nor the other. I have just made this crystalline body the subject of a little investigation, preparing it by the action of ammonia on lead cyanate, and have discovered it to be nothing else than urea." Now urea

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is a very constant product of animal excretion. More than 80 per cent of the nitrogenous products present in the urine consist of urea. If, therefore, any compound could be called organic, that distinction would surely belong to the urinary compound. And yet, as Wöhler had shown, it could be made quite easily in the chemist's laboratory. Soon afterwards, a number of other compounds, supposedly organic, were prepared by chemists; and to-day the chemist does not hesitate to prepare cane sugar, to synthesize a fat, and even to build up a substance resembling a protein. He will admit no mysterious force to reside in any one of the thousands of compounds in nature. And though we still retain the phrase "organic chemistry," all we mean by it is the chemistry of the carbon compounds.

The carbon compounds still constitute a separate chapter in chemistry because there are so many of them as compared to compounds other than carbon. Incidentally, it is also true that carbon compounds play a prominent rôle in the vegetable and animal world. But there is no reason to suppose that the activities of a cell, the unit of life, are any less de-

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pendent upon the presence of mineral or inorganic constituents and upon water.

Wöhler, though he synthesized urea and made other notable discoveries in organic chemistry, gradually drifted into inorganic chemistry and actually isolated for the first time the element aluminum, whose popularity in our day is overshadowed only by iron. But his life-long friend, Liebig, with whom he published several notable papers, remained true to organic chemistry; or rather, shall we say, to organic chemistry as applied to agriculture and physiology. Liebig is considered the father of scientific agriculture; for he it was who showed the importance of potash and phosphorus for the growth of plants. His views in the realm of physiology and his ideas concerning fermentation were disputed by two Frenchmen, Claude Bernard and Pasteur; and the victory undoubtedly belongs to the Frenchmen; but Liebig did start people thinking along these lines, as he did along so many lines.

Liebig and Wöhler were life-long friends. They were not only great masters who founded great schools in Germany, but for many years they worked

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together; and their correspondence, covering some forty years, is substantially a history of chemical progress during these years. Liebig was professor at Giessen and Wöhler professor at Göttingen. "I had the good fortune," wrote Liebig in an autobiographical sketch, "to gain a friend of similar tastes and similar aims, with whom, after so many years, I am still knit in the bonds of warmest affection. While in me the predominating inclination was to seek out the points of resemblance in the behavior of bodies or their compounds, he possessed an unparalleled faculty of perceiving their differences. A keenness of observation was combined in him with an artistic dexterity, and an ingeniousness in discovering new means and methods of research or analysis such as few men possess. The achievement of our joint work on uric acid and oil of bitter almonds has frequently been praised; it was his work. I cannot sufficiently highly estimate the advantage which the association with Wöhler brought to me in the attainment of my own as well as our mutual aims, for by that association were united the peculiarities of two schools—the good that was in each became effective by coöperation. Without envy and without jealousy, hand in hand we pursued our way; when the one needed help,

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the other was ready. Some idea of this relationship will be obtained if I mention that many of our smaller pieces of work which bear our joint names were done by one alone; they were charming little gifts which one presented to the other."

A remarkable friendship, this, between two of the foremost chemists of their time. Each was a genius, but Liebig was volatile and full of fireworks, and Wöhler was the gentlest of souls. And it was Wöhler, with his Goethe-like philosophy, who calmed and soothed his fiery friend. "P—— is a fool, *mon cher*," writes Liebig to Wöhler. "He now knows what he has need to be told—and trembles. All the bile which had been concentrating in me on his account I have now poured out upon him. . . ." Whereupon the gentle Wöhler writes a letter which is surely worth preserving: "To make war upon —— is of no use. You merely consume yourself, get angry, and ruin your liver and your nerves—finally with Morrison's Pills. Imagine yourself in the year 1900, when we shall both have been decomposed again into carbonic acid, water and ammonia, and the lime of our bones belongs perhaps to the very dog who then dishonors our grave. Who then will care whether we lived in peace or in strife? Who then will know anything

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about your scientific controversies—of your sacrifices of health and peace for science? No one; but your good ideas, the new facts you have discovered, these, purified from all that is unessential, will be known and recognized in the remotest times. But how do I come to counsel the lion to eat sugar!”

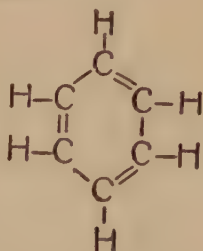
In so far as the public is concerned, Liebig would have long been forgotten but for his beef extract!

The schools founded by Liebig and Wöhler grew to immense proportions, and their students spread and extended organic chemistry over wide areas. But difficulties soon arose. It is true that Liebig had developed a method of organic analysis which, in its essentials, is used to this day. But such an analysis still left much unsaid. To illustrate in a very crude way—for we are here touching a rather technical phase of the subject—a compound is shown to have the formula C_2H_6O . It may be grain alcohol, or it may be a certain type of ether. Kekulé's suggestion of structural formulas has paved the way for showing us how two such substances can be represented in two-dimensional space. The alcohol be-

comes
$$\begin{array}{c} \text{H} \quad \text{H} \\ | \quad | \\ \text{H}-\text{C}-\text{C}-\text{O}-\text{H} \\ | \quad | \\ \text{H} \quad \text{H} \end{array}$$
 and the ether
$$\begin{array}{c} \text{H} \quad \quad \text{H} \\ | \quad \quad | \\ \text{H}-\text{C}-\text{O}-\text{C}-\text{H} \\ | \quad \quad | \\ \text{H} \quad \quad \text{H} \end{array}$$

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Now this may be quite meaningless to the non-scientific reader, but to the chemist it epitomizes a bookful of knowledge. What is even more to the point is that without Kekulé's theories, the development of organic chemistry would have come to a standstill, and much of what the chemist can do to-day in manufacturing dyes and drugs would have been quite impossible. This is more particularly true of Kekulé's work on the structure of benzene, which is the mother substance of more than one-half of all organic compounds. Benzene has the formula C_6H_6 ; and it was Kekulé who first suggested that its properties and the properties of its derivatives could best be expressed by assigning to benzene a *hexagonal, closed-ring* structure:



We are told by Kekulé himself that the germ of these ideas which were to revolutionize organic chem-

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istry came to him as a result of no little daydreaming. One fine evening, he tells us, during his stay in London, he took a ride on top of an omnibus and soon fell into a reverie. The atoms "began to gambol" before his eyes. By the time the conductor cried out "Clapham Road" and Kekulé awoke to the world around him, the outline of the theory was already clear to him.

On another occasion, he tells us, "I was sitting, writing at my text-book, but the work did not progress; my thoughts were elsewhere. I turned my chair to the fire and dozed. Again the atoms were gamboling before my eyes. My mental eye, rendered more acute by repeated visions of this kind, could now distinguish larger structures, of manifold conformation: long rows, sometimes more closely fitted together, all twining and twisting in snake-like motion. But look! What was that? One of the snakes had seized hold of its own tail, and the form whirled mockingly before my eyes. As if by a flash of lightning I awoke; and this time also I spent the rest of the night in working out the consequences of the hypothesis."

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"Let us learn to dream, gentlemen," adds Kekulé, "then perhaps we shall find the truth . . . but let us beware of publishing our dreams before they have been put to the proof by the waking understanding."

Kekulé (1826-1896) the prophet whose dreams came true, spent most of his years as professor of chemistry at the University of Bonn; and one of his pupils, whom we shall refer to later in the book, van't Hoff, extended the master's views on structural chemistry to explain phenomena which could not otherwise be explained. Van't Hoff published his views in a book called *The Arrangement of Atoms in Space*, one of the classics in the science. But it was considered anything but a classic by some of his contemporaries. Kolbe, a distinguished chemist of the time, begins a review of the book in the following vein: "A Dr. van't Hoff of the Veterinary College in Utrecht, appears to have no taste for exact chemical research. He finds it a less arduous task to mount his Pegasus and to soar to his chemical Parnassus, there to reveal in his *La Chimie dans l'espace* how he finds the atoms situated in the world's space. . . . It is not possible, even cursorily, to criticize this

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paper, since its fanciful nonsense carefully avoids any basis of fact, and is quite unintelligible to the calm investigator. . . .”

The possibilities of structural chemistry can find no more beautiful illustration than in the work of Emil Fischer (1852-1919) and Richard Willstätter (1870-). Fischer, for many years professor at the University of Berlin, worked out the chemical structures of the sugars, the purines (of which caffeine is an example), and, to a large extent, the proteins. Willstätter, who is still active, and who has recently resigned his chair of chemistry at the University of Munich, is responsible for a masterly investigation into the chemistry of chlorophyll, the green leaf pigment, and for an equally brilliant investigation into the blue and red pigments of flowers.

Structural chemistry, as developed by Kekulé and van't Hoff, has made it possible for Pictet in Geneva to synthesize cane sugar and for Windaus in Göttingen to prove that ergosterol is the mother substance of vitamin D. These are discoveries of the last year or two.

And while organic chemistry was growing to its present stage, Napoleon conquered and was con-

WÖHLER

quered, Fulton steamed, Morse telegraphed, Faraday made a dynamo and Bessemer made steel possible, Darwin published his *Origin of Species*, Pasteur, Koch and Lister gave a new meaning to the word "disease," the Crimean War and the Civil War and the Franco-German War were fought, Edison appeared with his phonograph, Hertz with his wireless, Röntgen with his X-rays, Madame Curie with her radium, the Wrights flew, and then—the Great War!

CHAPTER XIII

PERKIN AND COAL-TAR DYES

THE organic chemistry which was discussed in the last chapter gave rise to large industries dealing with dyes and drugs. Perkin (1838-1907) is considered the father of the dye industry, and it is Perkin and Perkin's pioneer work which we now wish to consider.

One of Liebig's pupils in Giessen was Hofmann, a very remarkable chemist and a very remarkable teacher. Eventually he became professor of chemistry at the University of Berlin, but much earlier in his career he accepted a position to head a college of chemistry founded in London. This school of chemistry did not last very long; but during its existence it exerted great influence. Hofmann's teaching and research attracted a number of promising pupils; among them was Perkin.

Perkin was not yet twenty when he was put upon the problem of making quinine artificially. But for the incomplete knowledge existing at that time,

PERKIN

neither teacher nor pupil would have begun work on this alkaloid so light-heartedly. As a matter of fact, Perkin got no quinine, but he did get something which eventually proved to be of immense industrial importance—the first dye to be obtained from coal tar.

Coal tar, a by-product obtained from the destructive distillation of coal, was a waste and a nuisance until Perkin's discovery. It is an evil-smelling and dirty-looking product, and manufacturers would pay money to have it carted away and dumped into the sea.

By distilling coal tar a number of products are obtained, and from one of these it is quite easy to get aniline. It is from aniline that Perkin obtained his first dye. It was in England that the coal-tar dye industry was first started, but it was Germany which took over this industry and developed it to its present stupendous proportions.

Perkin, in the course of his experiments, treated aniline sulphate with potassium dichromate. An unpromising black precipitate was obtained, but out of this material the young man isolated a dye which afterwards became known as aniline purple, or

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mauve. "All these experiments were made during the Easter vacation of 1856 in my rough laboratory at home. Very soon after the discovery of this coloring matter, I found that it had the properties of a dye, and that it resisted the action of light remarkably well."

Though not more than eighteen years old, Perkin quickly recognized the industrial possibilities of his discovery. He took out a patent; he told Hofmann, much to the professor's disgust, that he was going into business, and without knowing anything about industrial conditions and technical requirements, he decided to build a factory.

The patent read: "The nature of my invention consists in producing a new coloring matter for dyeing with a lilac or purple color stuffs of silk, cotton, wool and other materials in the manner following:

"I take a cold solution of sulphate of aniline, or a cold solution of sulphate of toluidine, or a cold solution of sulphate of xyloidine, or a cold solution of sulphate of cumidine, or a mixture of any one of such solutions with any others or other of them, and as much of a cold solution of a soluble bichromate as contains base enough to convert the sulphuric acid

PERKIN

in any of the above-mentioned solutions into a neutral sulphate. I then mix the solutions and allow them to stand for ten to twelve hours, when the mixture will consist of a black powder and a solution of a neutral sulphate. I then throw this mixture upon a fine filter and wash it with water till free from the neutral sulphate. I then dry the substance thus obtained at a temperature of 100° C. or 212° F., and digest it repeatedly with coal-tar naphtha, until it is free from a brown substance which is extracted by the naphtha. Any other substances than coal-tar naphtha may be used in which the brown substance is soluble and the coloring matter is not soluble. I then free the residue from the naphtha by evaporation, and digest it with methylated spirit, or any other liquid in which the coloring matter is soluble, which dissolves out the new coloring matter. I then separate the methylated spirit from the coloring matter by distillation, at a temperature of 100° C. or 212° F."

The factory was built in June, 1857. His father and his brother, both supremely confident in the boy, but with little idea of the difficulties to be encountered, joined him in the undertaking. "At this time," writes Perkin, "neither I nor my friends had seen

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the inside of a chemical works, and whatever knowledge I had was obtained from books." What a rare combination of ignorance and audacity which spurred him on!

From the start there were mechanical and chemical difficulties. New kinds of apparatus were required, large quantities of solutions, but little used until then, were also needed. Nitrobenzene had to be prepared, for example. For this purpose, benzene and nitric were needed. But the amount of benzene which could be obtained in the open market was quite limited and the nitric acid was not strong enough. When these difficulties were overcome, the type of apparatus to be used had to be devised and tried out. Perkin was the first to prepare nitrobenzene in iron vessels. To get the aniline from the nitrobenzene, the latter was treated with finely divided iron and acetic acid, and here again many difficulties had to be overcome. When, eventually, some of the dye, the mauve, was prepared and used by "Mr. Keith" in his dye-house to dye silk, the unevenness of the dye on the material made Mr. Keith very skeptical, and at this point the situation was saved by the discovery that all un-

PERKIN

evenness disappeared if the dyeing was done in a soap bath. By the use of a suitable mordant (tannin and a metallic oxide) the mauve could also be applied to cotton, and in this way the use of the dye was considerably extended.

Perkin had paved the way and others followed. Two Germans, Graebe and Liebermann, showed us how to obtain alizarin artificially—the first example of the artificial preparation of a vegetable coloring matter. Then, later, came the great Baeyer himself, who showed how the most famous of dyes, indigo, could be made in the laboratory. Baeyer worked quietly in his laboratory at the University of Munich; but the Badische Aniline und Soda-Fabrik, that vast industrial organization, undertook to convert the results of the laboratory into those of the factory, and after years of further research, artificial indigo finally appeared on the market at a price which made the further growth of the indigo plant in India not profitable.

It may be said without exaggeration, that the majority of industrial processes involving organic chemistry owe a debt of gratitude to the pioneer work

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of Perkin. And often enough, even processes which are not "organic" have become possible only because of the experience gained in manufacturing dyes and drugs. It was in Germany that the importance of Perkin's discovery was most quickly recognized, and it was the Germans who developed its possibilities to the highest degree. Much of Germany's greatness prior to the Great War was the result of this intensive application of Perkin's discovery.

In 1874 Perkin sold his factory and from then on devoted himself to pure scientific research, in which field he made valuable contributions. When, in 1906, the English Chemical Society celebrated the fiftieth anniversary of the founding of the coal-tar industry, the committee published a report in which we find the following passage: "That you should have been able, as a very young man, to overcome the extraordinary difficulties incident to the establishment of an entirely novel industry 50 years ago is a clear proof that you were possessed in an unusual degree of courage, independence of character, judgment and resourcefulness; but even more striking is your return into the fold of scientific workers and the ardor with which you have devoted yourself to

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the prosecution of abstract physico-chemical inquiries of exceptional difficulty.”

One of Perkin's sons is the present incumbent of the chair of organic chemistry at Oxford. He is generally considered England's foremost organic chemist.* The gods were kind to Perkin.

* Professor Perkin has died since this was written.

CHAPTER XIV

ARRHENIUS AND THE THEORY OF ELECTROLYTIC DISSOCIATION

WE have touched upon organic chemistry, and now we must approach another branch of the science which is even more recent in its development. It is called physical chemistry, and, as its name implies, attempts to introduce certain quantitative data obtained by the physicist into chemistry. It attempts to make chemistry less descriptive and more scientific.

In a sense, the founders of this science are three in number—van't Hoff, Arrhenius and Ostwald. Van't Hoff (1852-1911) was a Dutch chemist whose acquaintance we have already made in connection with structural organic chemistry. He, however, became primarily interested in what is known as the kinetics of chemical action—the velocity, in other words, of chemical action, and in connection with this interest, he speculated upon the nature of solutions. Most chemical action, as we know, takes place in

ARRHENIUS

solutions—in the dissolved state, and it was but natural that the nature of solutions should be studied.

The great contribution to the subject of solutions was, however, made by Arrhenius (1859-1926), a Swedish chemist, and as his theory of electrolytic dissociation has so largely influenced modern chemical thought, some idea of its content must be given.

What happens, we may ask, when salt is dissolved in water? We see the salt disappear and we become aware that the salt distributes itself uniformly throughout the solution. By evaporating the water we can, if we wish, recover the salt. But in what state is this salt when dissolved in water? Van't Hoff from his studies on osmotic pressure (a phenomena of interest to botanists and physiologists), said that the salt, in solution, behaves as if it were in the form of gaseous molecules.

Arrhenius classified solutions into two classes: those which conduct a current (electrolytes) and those which do not conduct a current (non-electrolytes). Of course, he did not overlook the fact that there were all shades in between these two extremes. Experiment shows that a sugar solution is a non-

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electrolyte and that a salt solution is an electrolyte. But why this difference?

Arrhenius ventured the suggestion that when you dissolve sugar in water, the sugar molecules remain intact; but when you do the same to salt, the salt molecule splits into two parts, the sodium ion and the chlorine ion, and it is the *ions* which make an electrolyte of the solution. An ion is the atom with an electric charge attached to it, so that if the formula for salt (sodium chloride) be given as NaCl , dissolving salt in water causes the production of Na^+ and Cl^- , the $+$ and $-$ representing positive and negative charges of electricity. The Na is a sodium atom, but the Na^+ is a sodium ion. The Cl is a chlorine atom, the Cl^- is a chlorine ion.

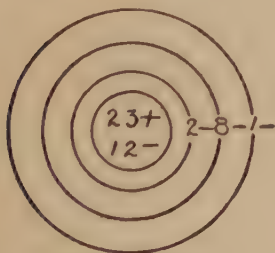
But where, he was asked, do the electric charges come from? From the molecule of sodium chloride itself, which is electrically neutral because it has an equal number of positive and negative particles of electricity. And what, then, does the current do when it is passed through a solution of sodium chloride? He answered: the sodium ion which is positively charged, is made to move to the negative pole, there becoming a sodium atom; the chlorine, which is

ARRHENIUS

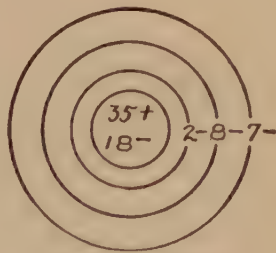
negatively charged, is made to move to the positive pole, there becoming a chlorine atom.

More recent work on the structure of the atom and on the behavior of compounds when submitted to X-ray examination, has somewhat modified these views of Arrhenius, and since this work gives a more concrete picture of what probably happens, we shall review it briefly here.

You may remember (page 74) how we constructed the structures of the atoms of sodium and chlorine in terms of their protons and electrons. Let us just picture them again:



SODIUM ATOM



CHLORINE ATOM

Sodium and chlorine can be made to combine to form sodium chloride, or common salt. Can we explain what happens in the course of this chemical union? We think we can. We believe that the outer-

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most electron (1^-) in the sodium atom leaves the sodium and attaches itself to the seven outermost electrons (7^-) of the chlorine atom, completing the more stable system of eight electrons. We can picture this result as follows:



SODIUM CHLORIDE

If, now, we add up the protons and electrons on the left, we find one proton (+) in excess; in other words, the neutral sodium atom (Na°), with an equal number of protons and electrons, has become the sodium ion (Na^+), with an excess of one proton. Similarly, an examination of the figure on the left reveals one electron ($-$) in excess. Here the chlorine atom (Cl°) has become the chlorine ion (Cl^-), remembering that the ion is the atom with an electrical charge attached to it, whether positive or negative.

X-ray studies of crystals of common salt have

ARRHENIUS

shown that there are sodium ions and chlorine ions in the very crystals, in a form—to put it very crudely—as shown in the above figure. Electrostatic forces bind the chlorine and sodium ions to one another. When, then, a crystal of sodium chloride is dissolved in water, there is no need of breaking up a molecule into ions—as Arrhenius originally postulated—for the ions already exist; but there is need of overcoming the electrostatic attraction between the ions and separating them into more or less independent units. This is the function of the water. The function of the electric current is, as Arrhenius suggested, to give direction to these ions.

If I have gone into some detail into the theory of electrolytic dissociation, it is only because in importance and influence it ranks with Dalton's Atomic Theory or with Mendeléeff's Periodic Classification of the elements. And now let us retrace our steps and see how this theory—the accepted theory of to-day—was first received by chemists and physicists.

Arrhenius, while a student first in Upsala and then in Stockholm, studied the electrical conductivity of solutions; and, like Kekulé, got inspirations in his dreams. It was in one of these dreams that the angel

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whispered to him that certain substances in solution dissociate (or break up) into ions. "I got the idea on the night of the 17th of May, 1883, and I could not sleep that night until I had worked through the whole problem. . . . I had deduced a rather great number of different properties which had not been explained before, but I must say that this circumstance made no very great impression upon my professor at Upsala. I came to my professor, Cleve, whom I admire very much, and I said, 'I have a new theory of electrical conductivity as a cause of chemical reactions.' He said, 'This is very interesting,' and then said 'Good-by.' He explained to me later—when I was presented with the Nobel Prize—that he knew very well that there are so many different theories formed, and that they are all almost certain to be wrong, for after a short time they disappear, and therefore by using the statistical manner of forming his ideas he concluded that my theory also would not exist long!"

Arrhenius looked around and saw none but unsympathetic faces. He thought that possibly foreigners might be more receptive, and so he wrote to two distinguished physicists, Clausius and Thomson, and

ARRHENIUS

to one rising chemist, Ostwald. Clausius and Thomson were little more encouraging than the Swedish professors, but Ostwald made up for all of them. Ostwald, at first professor at Riga and later at the University of Leipzig, was himself very much interested in physico-chemical problems; and what was even more fortunate for Arrhenius, he became one of the most powerful and convincing exponents of the newer theories. In later years Ostwald was fond of relating how Arrhenius's letter arrived on the day when he happened to suffer from a wretched toothache and on the day when his wife presented him with a daughter. "That was too much for one day. The worst was Arrhenius's letter, for the others developed quite normally!"

In 1887, Arrhenius's paper, properly expanded, together with van't Hoff's paper on osmotic pressure, were published in the first number of the first volume of the *Zeitschrift für physikalische chemie*, which Ostwald had founded, and in this way the new theories concerning solution obtained wide publicity, though not yet wide recognition. Even as late as 1890, at a British Association meeting, the opponents were in very full force, and it is recorded how in the

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course of a luncheon, one Englishman, with a plate of soup in his hand, rushed up to Ostwald to ask, in a very excited tone, whether atoms of sodium and chlorine were floating in his soup. "No, not atoms," replied Ostwald calmly, "but ions." "Ions! rubbish!" came the reply.

However, owing possibly to Ostwald's growing influence, the chair of chemistry at Giessen becoming vacant the following year, Arrhenius was nominated for a post long held by Liebig himself. But Arrhenius declined, returned to Stockholm and, much later, became Director of the Nobel Institute.

Aside from purely physico-chemical problems, Arrhenius became interested in matters pertaining to the origin of life, and in the application of physical chemistry to biology. "Biological chemistry," he wrote, "cannot develop into a real science without the aid of the exact methods offered by physical chemistry. The aversion shown by biochemists, who have in most cases a medical education, to exact methods, is easily understood. . . . The physical chemists have found that the biochemical theories, which are still accepted in medical circles, are founded on absolutely unreliable bases, and must be replaced by other no-

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tions agreeing with the fundamental laws of general chemistry."

His speculations on the origin of life dealt not so much with origin as with the appearance of life on the planet. He advanced the theory that seeds of life (spores), drifting in interstellar space, occasionally might come in contact with planets where, if conditions were favorable, life might ultimately appear. "The loss of vitality in interstellar space at 220 degrees below zero would be more than one hundred million times less rapid than the loss at ten degrees, which means that a journey of three million years through space would be no more injurious than a single day of exposure to terrestrial spring temperature."

CHAPTER XV

THE Curies AND RADIUM

THE discovery of radium has revolutionized physics and chemistry. Here Nature for the first time has provided us with an element whose atoms are constantly undergoing decomposition, giving off at the same time different types of rays, and also energy in the form of heat. It has given us our first insight into the structure of the atom, to which reference has already been made once or twice. It has created a new science, radioactivity, which deals with reactions *within* the atom, as compared to chemistry, which deals with reactions *between* atoms.

This glorious discovery of radium, and much of its associated phenomena, radioactivity, we owe primarily to Madame Curie. I shall offer no apology for discussing this discovery in some detail.

Early in the nineties of the last century, Roentgen discovered the X-rays, a discovery which meant as much to the progress of medicine as to that of physics. This was a sensational discovery and created a pro-

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found impression in lay as well as in scientific circles. Everybody began to play with X-rays, and everybody tried to get these X-rays in all sorts of ways. One of the men who became interested in the work of the Munich professor was Henri Becquerel, a French physicist, who studied uranium salts in the hope of showing some connection between fluorescence and X-rays. Becquerel discovered no such connection, but he did make an unlooked-for discovery of momentous consequence. He happened to place the salt of uranium upon a photographic plate, which, in turn, was covered with black paper. Despite the fact that the photographic plate was not exposed to light, an impression was formed, just as if light had acted upon it. Becquerel soon concluded that this impression, or sensitization of the plate, must be due to rays emitted by the uranium, which rays have the power of traversing paper.

At this time Madame Curie and her husband were working together at the University of Paris. They had heard of Becquerel's discovery and were fascinated by it. As Dr. Curie was busy with his own somewhat abstract researches in physics, Madame

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Curie decided on her own initiative to make a more careful examination of these Becquerel rays.

Since these rays ionize the air about them, it was possible, by the use of a modified gold-leaf electroscope, to measure the intensity of this radiation. Madame Curie soon showed that the intensity of this radiation was strictly proportional to the amount of uranium employed; and that light and heat had no effect whatever.

She next examined various elements and compounds in order to find out whether substances other than uranium showed any such property. Only one substance did, and that was thorium. Here again the property of giving off these peculiar rays was due to the thorium present and was quite independent of other substances which might be combined with the thorium; and also, the intensity of the radiation was directly proportional to the amount of thorium employed.

That heat should have no effect upon the rate of ray production was significant, because it at once suggested that we were here dealing with a phenomenon not chemical, for all chemical reactions are influenced by temperature. This phenomenon of ray emission

THE Curies AND RADIUM

by uranium and thorium Madame Curie named "radioactivity." Notice that this name radioactivity was coined before the element radium was isolated.

Her next observation proved pregnant with possibilities. She investigated several minerals which are the source of uranium and thorium, and discovered that a number of them showed a ray-emitting power which was greater than their content of uranium or thorium would warrant. "I then made the hypothesis that the ores of uranium and thorium contain in small quantity a substance much more strongly radioactive than either uranium or thorium. This substance could not be one of the known elements, because these had already been examined; it must therefore be a new chemical element. I had a passionate desire to verify this hypothesis as rapidly as possible. And Pierre Curie, keenly interested in the question, abandoned his work on crystals to join me in the search for this unknown substance."

They selected pitchblende as the ore from which the "new chemical element" was to be abstracted. This ore was four times more active than uranium itself. The procedure of decomposing the ore, separating it into various fractions and then testing each

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fraction was a laborious one. Each fraction was tested for its radioactive properties by means of the electroscope, and in this way many fractions could either be discarded or retained. It was possible, eventually, to show that the radioactivity resided in two fractions, the bismuth fraction and the barium fraction—so named because the salts of bismuth and barium, respectively, were the most abundant substances present.

In July, 1898, the Curies announced the existence of a new element, polonium (named after Madame Curie's native country), and in December of the same year, radium, another element, was described.

While spectroscopic examinations of concentrated fractions left no doubt of the existence of these two new elements, it was important actually to isolate them, and this had not, as yet, been done. Since these elements were present in pitchblende in the merest traces, the necessity for starting with large quantities of the ore was obvious. Practically all of the ore was obtained from a mine in St. Joachimsthal, Bohemia, which was owned by the Austrian Government, and which was worked for the extraction of uranium. Through the influence of the Vienna Academy of

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Sciences, the Government sold several tons of pitchblende to the Curies at a rather low figure; but some of this money had to come from their none-too-well-filled purses. Neither were the French university authorities too eager or able to supply them with adequate quarters in which to carry on the work. For two years the Curies worked upon the radium in an abandoned storeroom in which there "were no hoods to carry away the poisonous gases thrown off in our chemical treatments." Finally some radium, in the form of one of its salts, was isolated in the pure state, and, without delay, many properties of this remarkable element were studied.

It was shown, for example, that radium emits three types of rays: the alpha rays, which are positively charged, and which are known to be helium ions; the beta rays, which are negatively charged, and which are electrons; and the gamma rays, which closely resemble the X-rays originally discovered by Roentgen. The movements of both the alpha and beta rays were shown to be affected by a magnet, but the gamma rays were not affected at all. All concentrated radium products showed spontaneous luminosity.

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"We passed our days in the laboratory," writes Madame Curie, "often eating a simple student's lunch there. A great tranquillity reigned in our poor, shabby hangar. Occasionally, while observing an operation, we would walk up and down, talking of our work, present and future. When we were cold, a cup of hot tea, drunk beside the stove, cheered us. We lived in a preoccupation as complete as that of a dream."

In 1903 Madame Curie presented her radium studies as a thesis for the degree of doctor of science. It is doubtful whether in the history of doctors' dissertations a more celebrated thesis was ever presented.

Further work showed that, weight for weight, radium is one million times as powerful as uranium in ray-yielding power. If, then, pitchblende is but four times as powerful as the uranium which it contains, and, if, as we know now, the greater ray-emitting power in the pitchblende is due to the presence of radium, it requires little calculation to form an idea as to the small quantities of radium that must be present in the ore.

Our investigators noticed quite early that radium

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evolves heat—enough heat per hour to melt its own weight of ice. And this heat-emitting power, due to the friction caused by the impact of the rays on the surrounding radium, seems, for all practical purposes, something that never ceases. They also noticed the physiological effects of radium—observations which have since led to the use of radium in therapeutics. Pierre Curie exposed his arm to the action of radium, with a resulting “burn” which required several months to heal. Becquerel could confirm this effect of radium on the skin because he also suffered from a “burn,” due to carrying a little radium salt, enclosed in a glass tube, in his vest pocket. Looking at this radium, Becquerel exclaimed: “I love it, but I owe it a grudge!”

Honors flew thick and fast. In 1903, the year in which Madame Curie presented her doctor of science thesis, the Royal Society of London conferred the Davy Medal upon the Curies, and, at about the same time, they, together with Becquerel, were awarded the even greater distinction of the Nobel Prize for physics. This Nobel Prize award was a godsend in one way: the money which went with the award, some \$20,000, eased their financial condition, which, at

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best, was very poor. But they also became popular, which Pierre Curie found less pleasant. "We have been pursued by journalists and photographers from all countries of the world," he wrote to a friend. "They have gone so far as to report the conversation between my daughter and her nurse, and to describe the black-and-white cat that lives with us." When he was informed that the Government wished to decorate him he promptly replied: "I pray to thank the Minister, and to inform him that I do not in the least feel the need of a decoration, but I do feel the greatest need for a laboratory." And he could well complain, for, despite his celebrity, he was still without adequate laboratory facilities.

In the midst of all their glory, a street accident to Pierre terminated the life of one of this immortal pair. We are told that on the 19th of April, 1906, he attended a reunion of university professors. When he left them, and as he was crossing the rue Dauphine, "he was struck by a truck coming from the Pont Neuf, and fell under the wheels. A concussion of the brain brought instantaneous death." Pierre was no more than forty-eight years old.

The death of Pierre Curie awakened sympathy

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throughout the land and throughout the world. The Government immediately nominated Madame Curie to a professorship and asked her to take over the position which Pierre Curie had occupied. This position she has filled to the present day. Rather belatedly the Government created a Radium Institute, consisting of the Curie and the Pasteur laboratories; and Madame Curie was put in charge of the former. "With my agreement," writes Madame Curie, "Pierre refused to draw any material profit from our discovery. We took no copyright, and published without reserve all the results of our research, as well as the exact processes of the preparation of radium. In addition, we gave to those interested whatever information they asked of us." These two, who could have made millions had they wanted to exploit their discovery, gave all to the world, and the world repaid them by giving them neither decent wages nor adequate working facilities.

Madame Curie herself was born in Warsaw, Poland, in 1867. She received her high-school education in her native town; she gave lessons, and for a time acted as governess in order to increase her slender means (for her father was a retired teacher and,

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needless to add, poor); and she took a rather dangerous interest in Polish affairs at a time when Poland was still part of the vast Russian Empire. In 1891 she joined her sister and brother-in-law in Paris, took a room near the University and began to study mathematics and physics in real earnest. What her life was like we can gather from this autobiographical sketch: "The room I lived in was in a garret, very cold in winter, for it was insufficiently heated by a small stove which lacked coal. During a particularly rigorous winter, it was not unusual for the water to freeze in the basin in the night; to be able to sleep I was obliged to pile all my clothes on the bedcovers. In the same room I prepared my meals with an alcohol lamp and a few kitchen utensils. These meals were often reduced to bread with a cup of chocolate, eggs or fruit. I had no help in housekeeping and I myself carried the little coal I used up the six flights."

And yet the girl was not unhappy, for she was absorbed in her work at the Sorbonne. She studied harder than the other students, not because she was less bright, but because her preparation in mathematics was poor as compared to the others. Despite

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this handicap, she graduated in first rank as *licenciée ès sciences physiques* in 1893, and in second rank as *licenciée ès sciences mathématiques* in 1894.

In 1894 she first met Pierre Curie. "Upon entering the room I perceived, standing framed by the French window opening on the balcony, a tall young man with auburn hair and large limpid eyes. I noticed the grave and gentle expression of his face, as well as a certain abandon of his attitude, suggesting the dreamer absorbed in his reflections. He showed me a simple cordiality and seemed to me very sympathetic. After that first interview he expressed the desire to see me again and to continue our conversation of that evening on scientific and social subjects in which he and I were both interested, and on which we seemed to have similar opinions."

He wrote to her: "It would be a beautiful thing in which I hardly dare believe, to pass through life together hypnotized in our dreams! Your dream for your country, our dream for humanity, our dream for science." They were married in July, 1895, Marie Skłodowska now becoming Marie Skłodowska Curie. On the munificent salary of 6,000 francs (\$1,200) which he received as professor in the school

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of physics and chemistry of the City of Paris, Pierre Curie and his wife rented an apartment in the rue de la Glacière overlooking a large garden. What a coincidence! The author of this book lived last year in the rue de la Glacière overlooking this very self-same garden! And at that time he was quite ignorant that the immortal pair had lived there too.

The life story from here on is one of struggle and work, work and struggle, with little relief even after their discovery of radium and their recognition by the world of science. Pierre was killed, leaving the mother with two young children. Eight years later came the World War and more suffering. Can you blame the woman when out of the bitterness of her heart she writes:

“What reward does our society offer the scientist? Have they the necessary means of work? Have they an assured existence, sheltered from care? The example of Pierre Curie, and of others, shows that they have none of these things; and that more often, before they can secure possible working conditions, they have to exhaust their youth and their powers in daily anxieties. Our society, in which reigns an eager desire for riches and luxury, does not understand the

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value of science. It does not realize that science is a most precious part of its moral patrimony . . . Humanity surely needs practical men who make the best of their work for the sake of their own interests, without forgetting the general interest. But it also needs dreamers, for whom the unselfish following of a purpose is so imperative that it becomes possible for them to devote much attention to their own material benefit. No doubt it could be said that these idealists do not deserve riches, since they do not have the desire for them. It seems, however, that a society well organized ought to assure to these workers the means for efficient labor, in a life from which material care is excluded, so that this life may be freely devoted to the service of scientific research."

CHAPTER XVI

CHEMICAL ANALYSIS

EVERY university and college has its professor of analytical chemistry. Analytical Chemistry, as its name implies, deals with the analysis and, therefore, the identification of substances. Without chemical analysis, chemistry would be at a standstill. Unless an "unknown" can be identified, new knowledge is out of the question.

While an outline of qualitative and quantitative analysis can hardly be given here, some insight into the subject, no matter how crude and superficial, must be offered.

In the first place, let us take up one or two elements, for they are much simpler to deal with than compounds. Priestley obtained a gas which had neither color, taste nor odor and which was slightly soluble in water. Certain substances, such as a lighted taper, burned in this gas much more vigorously and with more brilliant illumination than in ordinary air. A gas with such properties we call oxygen. To be

CHEMICAL ANALYSIS

sure, the chemist of to-day would require a more rigorous analysis of the gas before he would admit that it was oxygen, but we here are interested more in the principle than in the details; and it is important for us to bear in mind that the element oxygen shows certain characteristic properties, with the help of which we can identify the gas. Every element and every compound is identified by making use of one or more of such characteristic properties which elements and compounds possess.

Scheele obtained a gas which was pale yellow in color, which had a suffocating odor and which was very heavy as compared to air, so that the gas had a tendency to collect near the bottom of the vessel. These are some of the characteristic properties of chlorine, with the help of which it may be identified.

On the other hand, when we deal with compounds rather than with elements, identification often becomes more difficult, for since every compound is composed of two or more elements, it may be necessary to decompose the compound and identify each one of the elements. Suppose our substance, solid and crystalline, is salty to the taste and an analysis shows it to contain sodium and chlorine, we would be justi-

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fied in suspecting that the substance is common salt, and confirmatory experiments could then be performed. Suppose our substance is a colorless liquid and on analysis yields oxygen and hydrogen, we might suspect the liquid to be water. As a matter of fact, peroxide of hydrogen is also a colorless liquid, and also yields nothing but oxygen and hydrogen when analyzed. One way of distinguishing these two substances is by a quantitative analysis, in contradistinction to a qualitative analysis; in other words, we would have to find out not only whether oxygen and hydrogen could be obtained by decomposition, but how much oxygen and how much hydrogen. Such a quantitative analysis would show that water is H_2O and peroxide of hydrogen H_2O_2 ; that is to say, that water contains two atoms of hydrogen for every one atom of oxygen, whereas peroxide of hydrogen contains two atoms of hydrogen for every two atoms of oxygen.

Let us dwell a moment longer on qualitative versus quantitative chemistry. Assume that you have two substances and that you submit each to a qualitative analysis. You find that they are both composed of the elements carbon, hydrogen and oxygen. Just

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how you can find this out is a rather long story and the account would be too technical to be given here; but the important point that we wish to bring out is that, in this particular instance, an elementary qualitative analysis fails to show any difference between the two substances. When, however, we submit them to a quantitative analysis, to determine how much carbon, hydrogen and oxygen they contain, then we discover that the formula for one of them is $C_6H_{12}O_6$ and the formula for the other, $C_{12}H_{22}O_{11}$; that one is, in reality, grape sugar and the other is cane sugar.

Thanks to the labors of Lavoisier, Berzelius, Liebig, Wöhler, Bunsen and others, schemes for the analysis of "unknowns" have been mapped out so that it becomes, as a rule, a comparatively simple procedure to identify a substance. Again without going into any details, a simple illustration can be given.

We have an unknown solution and the directions tell us to add a little hydrochloric acid. We get a white precipitate, and the direction tells us that a white precipitate at this point indicates the presence of silver, lead or mercury salts. But how are we to know which of the three is our "unknown"? Again the directions inform us that if the precipitate is a

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lead salt it will dissolve when heated with water; if it is a silver salt, it will dissolve upon the addition of ammonia; if it is a mercury salt, it will turn black on adding ammonia. Where a "positive" test is obtained, the directions will next tell us of "confirmatory" tests, so as to make certain that the substance is actually what we think it to be.

In quantitative analysis, the balance is a very important instrument. You may remember that it was Lavoisier who first made frequent use of the balance and who, with its means, helped to build up the science of chemistry. But weighing is no more important than measuring: both emphasize quantitative relationships.

CHAPTER XVII

LE CHATELIER AND THE APPLICATION OF PURE SCIENCE TO INDUSTRY

RESearch in pure science is the prelude to research in applied science. Faraday's work on induced currents led to the development of the dynamo and Hertz's work on his Hertzian waves led to wireless. These examples could be multiplied endlessly. What is true of physics is true of chemistry: it is research in the laboratory which, sooner or later, leads to industrial applications; and what is equally important, the development of industrial processes is often quite impossible unless based on certain theoretical considerations. In this chapter we will show that one of the most important industries would be at a standstill but for the researches of the retiring professor in his laboratory.

A problem of outstanding importance deals with "nitrogen fixation." Here attempts are made to "fix" nitrogen, or to get nitrogen from the air in such a form as to make it available for plants. For plants

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need nitrogen; without it they do not flourish; but nitrogen in the elementary form, as found in the air, is quite useless to them. They must get their nitrogen in the form of some non-toxic, soluble compound containing the element.

This situation is similar to that found in the animal kingdom. Man needs nitrogen to live and to thrive, but the nitrogen of the air which he breathes in is exhaled unchanged. He makes use of nitrogen in the form of proteins, which he finds in many of the foods he eats.

Now, to be sure, you can spread animal refuse on the soil, and the soil will become fertile because animal refuse contains nitrogen in a form which the plant can use. But the amount of such animal waste is limited and it little suffices for the millions and millions of acres which await cultivation. For years this deficiency has been met by supplying farmers with Chile saltpeter, chemically known as sodium nitrate, which, as its name suggests, contains nitrogen as a constituent. This sodium nitrate is found in enormous quantities in Chile, and this country has been sending its nitrate to the four corners of the globe.

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But the deposits of Chile saltpeter, like the deposits of coal and oil, are not inexhaustible. Millions of tons are withdrawn, but none are replaced. And the question has often been raised, "What will happen to agriculture, and to life upon this planet, when the Chile deposit has been exhausted?"

The problem was a serious one. Neither statesman nor financier could offer a solution. But a solution was found by the chemist, and, let it be emphasized at this point, by the professor working in his laboratory.

The obvious source of nitrogen is found in the air. Roughly, some 80 per cent of the air we breathe is nitrogen. The problem which the chemist had to solve was how to extract this gas from the air and how to cause it to combine with other elements to form an available nitrogenous compound. Several methods have been devised in recent years, but the most successful is known as the Haber process, and it is to this process that we direct attention.

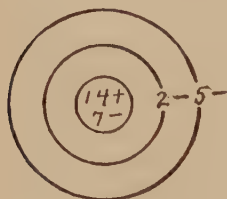
Haber, still alive and active, began his researches a number of years before the World War, while professor at the Polytechnic School in Karlsruhe, Germany. His goal was to get ammonia, NH_3 , by the

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direct union of nitrogen and hydrogen. Once obtained, this ammonia, in the form of any of its salts, proves an excellent fertilizer.

Now nitrogen and hydrogen can be made to combine, but the yield obtained is ridiculously small. So that methods had to be worked out for increasing the yields, and here the profound theoretical studies of such professors as Guldberg and Waage in Norway, Willard Gibbs in America and Le Chatelier in France made the problem possible of solution.

If we examine the atomic structures of nitrogen and hydrogen,



NITROGEN



HYDROGEN

and if we recall the discussion in previous chapters, one would expect, under appropriate conditions, that three hydrogen atoms would combine with one nitrogen atom; because each hydrogen atom has but one electron in its outermost ring, and three such elec-

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trons would be necessary to add themselves to the five electrons already present in the nitrogen atom to form a stable "octet" of eight electrons. The formula for ammonia, which is the compound formed when nitrogen and hydrogen combine, should be NHHH , or, more conveniently written, NH_3 ; and analysis actually shows it to be so.

We have said that nitrogen and hydrogen do combine, but in very small quantities, and Haber's aim was to improve the yield. If the process were to find industrial application, if it were to solve an important economic problem, it was necessary to devise a method by which a maximum yield was obtained at the expense of a minimum of effort.

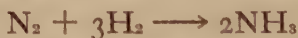
Haber asked himself, what are the ways in which I can cause more nitrogen and hydrogen to combine with one another? In the first place, we must remember that these gases are made up of millions and millions of molecules, and the more molecules of nitrogen are brought in contact with molecules of hydrogen, the more likely is it that a large percentage of these two gases will combine.

But how can the molecules be brought into more intimate contact? One way is by compressing the mix-

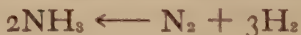
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ture of gases. This increased pressure reduces the space between the molecules and so brings them nearer to one another. Another way—and this can often be used in conjunction with pressure—is to increase the temperature; here the velocity of the molecules is increased and in this way they are more apt to come in contact with one another. Still a third way—which also may often be used in conjunction with the other two—is by the use of a catalytic agent. It has been found that the velocity of many reactions can be increased by introducing some substance, found by trial and error. This substance, if successful, speeds up the reaction, but apparently undergoes no permanent change itself. Such a substance is called a catalytic agent (catalytic means contact), and the process is known as catalysis.

But Haber's troubles were by no means at an end. He had to remember that most chemical reactions tend to be reversible, that nitrogen and hydrogen combine to form ammonia, to be sure:



but ammonia, in turn, has a very unpleasant tendency to decompose again into its elements:



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and to show this reversible tendency, we usually write such a reaction:



Obviously we want ammonia and we do not want to get our starting materials back again. We have to discover, then, a way of preventing the "back," or "reversible," reaction. Fortunately for Haber and for the science of chemistry, Le Chatelier developed a principle which is of the most general application. The principle may be stated in some such form as this: if an outside force is applied to a system in equilibrium, then the system will so adjust itself as to tend to neutralize the effect of this outside force. The application of this principle to the synthesis of ammonia may make it clear. In the reaction,



experiment shows that one volume of nitrogen combines with three times this volume of hydrogen to form two volumes of ammonia. Four volumes of the mixed gases are, in other words, reduced to two volumes of ammonia. We may now ask ourselves, what will be the effect upon this reaction of increasing the pressure? Will more of the reaction go from left to right? Will more ammonia be formed? If we

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apply the Le Chatelier principle, we see that the "outside force" in this case is pressure. There must be such a readjustment as to neutralize the effect of this pressure. In the reaction, four volumes of mixed gases are reduced to two volumes of ammonia—a process which would tend to neutralize the effect of the outside pressure. Hence, increased pressure, according to Le Chatelier, would tend to increase the reaction from left to right, which is just what we want. Therefore, in the actual manufacture of ammonia by the Haber process, high pressure is used.

Now what about the temperature—will increased temperature also favor the reaction from left to right? Actually when nitrogen and hydrogen combine to form ammonia, a considerable amount of heat is evolved; and the Le Chatelier principle teaches us that increased temperature would only make the reaction go from right to left if there were an absorption of heat, and not an evolution of heat. Hence increasing the temperature of this reaction beyond a certain minimum amount would prove fatal: it would give rise to less and less ammonia and more and more nitrogen and hydrogen, our starting substances.

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Since a catalyst will increase the speed of this reaction, and since "time is money," a catalyst is invariably employed. It took years of experimental work to discover which particular substance was the best catalyst. It took more years of labor to apply Haber's work to large-scale operations; here many of the difficulties were overcome by the engineer.

We are told that "in 1913, 56 per cent of the world's production of nitrogen was provided by Chile saltpeter, 37 per cent by nitrogen compounds obtained from coal, and only 7 per cent by synthetic nitrogen compounds (such as the Haber process). In 1925 only 30 per cent of the total production came from Chile saltpeter and 44 per cent from synthetic nitrogen compounds!" The chemist has certainly justified his existence!

We may point out, in passing, that the Haber process not only paves the way for an inexhaustible supply of nitrate fertilizer, but it also—shall we add unfortunately?—paves the way for the manufacture of high explosives. Ostwald, whose acquaintance we made in a previous chapter, devised a method for converting ammonia into nitric acid, and nitric acid, in turn, is the mother substance of the various nitro

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compounds which go to make up explosives. It was Haber who prevented Germany from starving early in the War, and it was Ostwald who supplied Germany with its ammunition. No wonder that the French were up in arms when Haber was awarded the Nobel prize in chemistry. (Haber, by the way, played a prominent part in the development of poison gases.) But we must stop damning the chemists because their discoveries are misused.

The Le Chatelier principle, we must again emphasize in concluding, is of the most general application, whether in pure science or in the industries. The Haber process is but one of countless chemical operations in which the intelligent application of this principle has turned failure into success.

Unfortunately, the "phase rule" of Willard Gibbs, another principle of general applicability, and not distantly related to the topics we have discussed, requires more than a modicum of physical and chemical knowledge; and all we can do at this point is to call the attention of the reader to the fact that there was such a man as Willard Gibbs, that he died not so long ago, that for years he was professor of mathematical physics at Yale, that few took any notice of him or

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his work during his lifetime, and that it was only when Ostwald and a few other Continental worshippers discovered him and hailed him as a master, that it began to dawn upon American scientists that Willard Gibbs is probably the foremost scientist America has so far given to the world.

CHAPTER XVIII

THE RISE OF BIOCHEMISTRY

WE have already seen in previous chapters how Lavoisier showed that there is a "burning" taking place in the body comparable to the burning of fuel, and how Wöhler synthesized urea, a typical body product. These and other discoveries gradually led to the view that the science of physiology could be much enriched by calling in the help of the chemist. The work of the chemist in the field of physiology (and in biology in general) has given rise to the rapidly developing branch of chemistry which is sometimes called biochemistry and sometimes physiological chemistry. It is the purpose of this chapter to give the reader some idea of the scope of this branch of the science.

The cell, the unit of life, had long ago been shown to consist of certain compounds, such as fats, proteins, carbohydrates, mineral salts, and also of water. These substances were common to all cells. While there are general reactions for proteins which distinguish

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them from fats or carbohydrates, it is also true to say that proteins differ very sharply among themselves; and so do the fats and the carbohydrates. So that when we say that cells have a number of constituents in common, we do not want to give the impression that cells cannot be differentiated. Obviously, there must be many different types of cells, and there must be many differences, if delicate differences, in the chemical make-up of the cells.

The substances in the cells, aside from water and the mineral salts, are quite complex; and it is no small tribute to the genius of the chemist, and to the efficiency of his analytical methods, to find that complex though they are, their mystery has been largely unraveled. Early in the last century the French chemist, Chevreul, showed that the so-called fats, whether obtained from butter, or olive oil, or meat fat, were combinations of glycerine and certain organic acids; and to-day it is no difficult matter to synthesize a fat in the laboratory.

Our knowledge of the chemical make-up of the sugars and proteins we owe very largely to the German chemist, Fischer, who died just a few years ago. In the field of sugar chemistry, so exact has be-

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come our knowledge, that quite recently the Swiss chemist, Pictet, succeeded in synthesizing cane sugar. The proteins are the most complex substances, chemically speaking, which exist. But even here Fischer succeeded, to a large extent at least, in unraveling their mystery; and here also Fischer was able to build up compounds which, in many ways, resemble the proteins found in nature. For you must bear in mind that an analysis is always followed by an attempted synthesis. If your analysis of the compound is correct, it should be possible to synthesize the compound, and often enough, the most convincing proof of the correctness of a formula, deduced by analytical means, is to synthesize the compound.

Not only are the cells composed of fats, proteins and carbohydrates, but the foods we eat are composed of the same substances. These foods of ours undergo "digestion" in the digestive tract preparatory to being absorbed by the small intestine. This digestion is brought about by "ferments," or "enzymes"; and the chemist has been busy investigating these substances. Some of the pioneer work in this field was done by the great Pasteur and by the

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Germans, Kühne and Buchner; but it must be admitted that much yet awaits elucidation. However, we do know this: that enzymes are catalysts, and that they are manufactured by certain cells of the body. We have already referred to a "catalyst" as a substance which influences a chemical reaction without itself being permanently changed; and enzymes belong to this group of substances, though, so far, no one has been able to make an enzyme artificially. In this respect the cell's secret has not, as yet, been disclosed to us. Indeed, it is highly questionable whether any enzyme has been obtained in the pure state.

The digested food finds its way into the blood, from where it travels to various cells to supply the material for the wear and tear of tissues; and waste material, on the other hand, is eliminated, much of it ultimately appearing in the urine. In this connection, the chemical analysis of blood and urine has become of great value to the clinician in his attempts at diagnosis, for the amounts of the several constituents differ at times quite markedly when normal and pathological cases are compared.

The chemist has developed many new methods for the estimation of urinary constituents; and he has

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had to devise micro methods for estimating blood constituents, since here the quantities of blood usually available are necessarily small. In this field three Americans, still alive, are preëminent: Professor Folin of Harvard, Professor Benedict of Cornell, and Dr. Van Slyke, of the Rockefeller Institute. It is their work, and the work of others, which has made it possible to show that in diabetes there is an increased sugar elimination, that in kidney disease the nitrogen constituents are affected, that rickets is usually accompanied by high phosphorus in the blood, and so on.

Side by side with the work of the organic chemist and the work of the analytical chemist, the work of the physical chemist has also been of great value. His outstanding contribution to biochemistry, so far, has dealt with the subject of body neutrality—with the various delicate mechanisms which confine the acidity of the blood, for example, to very narrow limits, and so make life possible. Here again we may point, with pardonable pride, to the work of two Americans, still living: Professor L. J. Henderson of Harvard, and Dr. Van Slyke, of the Rockefeller Institute—the

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same Van Slyke who is also preëminent in the analytical phase of biochemistry.

Another problem which has engaged the attention of chemists is the general subject of physiological oxidations. Lavoisier, we have pointed out, showed that there is a "burning" in the body; but how this burning is brought about he did not know. In the stove a substance like coal or wood burns to carbon dioxide and water; but such a burning involves a very high temperature indeed. If we were to attempt to convert sugar or fat to carbon dioxide and water, but outside of the body, a very high temperature would also be necessary. Yet sugar and fat are converted in the body to carbon dioxide and water at body temperature, which is around 37 degrees centigrade or 98 degrees Fahrenheit. How are such changes brought about at so low a temperature? Here, also, it has been shown that enzymes—the body catalysts—play an essential part, that their function is to accelerate such changes at comparatively low temperatures.

Several years ago Professor Hopkins, of Cambridge, succeeded in isolating in the pure state a sub-

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stance which is involved in body oxidation. He obtained it from various tissues, animal and vegetable, and even succeeded in synthesizing it. Around this glutathione—for that is the name given to the substance—much activity centers.

The two Germans, Meyerhof and Warburg, of the Kaiser Wilhelm Institute in Berlin, have also done notable work in this direction. Warburg, in particular, has been able to show that the type of oxidation (or “combustion,” or “burning”) which goes on in the cancer cell is different from that taking place in the normal cell. While this discovery has, at present, little clinical significance, yet the mere fact that we have been able to show chemical differences in the cancerous, as compared to the normal, cell, augurs well for the future.

The chemist has also made valuable contributions to the field of nutrition. First there were discussions as to calorific needs—as to the amount of calories needed by man. This involved the construction of calorimeters, and the measurement of the heat evolved when foods are oxidized, and the measurement of the heat evolved by man during the course of twenty-four hours. From such data, calo-

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rific needs were deduced, and various elaborate lists were published of foods and their calorie content. The foundations were built by Voit, Pettenkoffer and Rubner in Germany and by Atwater, Benedict and Lusk in America.

Next came questions as to the distribution of the various foodstuffs in the diet. Of what percentage of protein should the diet consist, for example? It may be said at once that this question still remains unsettled, violent partisans being found in the high and low protein camps. But the beautiful work of Osborne and Mendel at New Haven has made it clear that one has to consider not so much the *amount* as the *kind* of protein. For proteins are made up of simpler units, called amino acids; and certain of these amino acids are absolutely necessary to life. Since proteins differ in the amount and in the number of such amino acids, it can be seen that equal quantities of two different proteins may have quite different physiological values.

In nutrition, our chemists have shown, mineral salts must be considered just as important as fats, proteins and carbohydrates. This seems strange at first glance. The ash in coal we consider a waste and

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a nuisance; and by ash we mean nothing else but mineral salts. But the ash in foods is all-important; the bones need calcium and phosphorus, the blood needs iron, the thyroid needs iodine, the body fluids need salt, etc.

But in this field, perhaps the most sensational discovery was that of vitamins. A number of names are associated with this discovery. There is first of all the Dutch investigator, Eijkman, who, working in the Dutch East Indies some eighteen years ago, discovered that one could induce beriberi in fowls by feeding them with polished rice; and beriberi had been a very prevalent disease among the Japanese and other Asiatics. Then Funk, a Pole, showed that yeast contains the curative factor, and in the course of some elaborate experiments, came as near isolating the vitamin from yeast as any one has done since his time. Hopkins, of Cambridge, next showed in a very graphic way the importance of vitamins in nutrition. He showed that if one were to isolate the various constituents of milk, and feed such constituents to rats, they would lose weight and develop pathological symptoms, unless a little whole milk were added to their diet. Obviously, there was some-

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thing in milk other than fat, protein, carbohydrate, mineral salts and water, which was important in nutrition, and this something Funk called "vitamin," to indicate its life-giving force. You will please notice that Hopkins did not isolate the vitamin; he merely detected it by the effects produced when absent from a diet. And it may be added that, aside from the rickets-curing vitamin, none of the other vitamins has so far been isolated in the pure condition.

From 1912 on the work of Osborne and Mendel at Yale, of McCollom at Wisconsin (now at Johns Hopkins) and of others made it clear that we had to deal with more than one vitamin. In fact, at present, six vitamins are known with a fair degree of certainty, and we are by no means certain that others will not be discovered.

The absence of these vitamins from a diet gives rise to what are known as food deficiency diseases; diseases, in other words, due to one or more specific deficiencies in the diet. The very idea of a disease due to a deficiency in the diet was novel, for we had always been led to believe that disease may arise either from some constitutional breakdown of the organism (as in diabetes), or from some germ (as in

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tuberculosis), or from a combination of both of these. Nevertheless, it could now be shown that when what has been called vitamin A was missing from the diet, an eye disease developed; that when vitamin B was missing, either beriberi or pellagra or both made their appearance; that the absence of vitamin C gave rise to scurvy, and of vitamin D, to rickets, and of vitamin E, to failure to reproduce.

The importance of the work of the chemist in this field was recently beautifully illustrated in connection with vitamin D, the rickets-curing vitamin. In rickets the bones are affected, and, as might be expected, the mineral metabolism, involving calcium and phosphorus, is disturbed. Usually the phosphorus in the blood is very markedly diminished. Anything which brings about a cure will cause an increase in the phosphorus of the blood, as the analytical chemist could show. The methods of curing this disease are several in number. You can give the patient cod-liver oil, or you can expose him to the action of the sun's rays, or, in one form of the disease, you can add some phosphorus, in the shape of one of its salts, to the diet. Workers in this country and abroad—the organic chemists—were able to show that the active

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constituent in the cod-liver oil was a substance known as cholesterol, provided this cholesterol was first irradiated—that is to say, provided it was exposed to the sun's rays or to ultra violet rays obtained from some artificial source. Upon closer examination, it was discovered that pure cholesterol was quite inactive. As ordinarily obtained, the cholesterol contains a small quantity of an impurity, in which resides all the activity. Out of this impurity the chemist finally isolated a substance, ergosterol, closely akin to cholesterol, which, when activated (by sun's rays or artificial rays) proved 2,000 times as powerful in its action as ordinary or "impure" cholesterol.

Aside from some details, the chemical make-up of ergosterol is quite well known, thanks to the labors of the German chemist, Windaus. Ergosterol is now regarded as the "mother-substance" of vitamin D, for all one has to do to ergosterol to convert it to vitamin D—to "activate" it—is to irradiate it. Apparently, irradiation must bring about some rearrangement of the atoms within the molecule, creating thereby a new compound. Such rearrangements are not unknown.

In connection with ergosterol and vitamin D,

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one of the most arresting discoveries in science of the last few years, several names come to mind: Dr. Hess of New York City, Professor Steenbock of the University of Wisconsin, Dr. Rosenheim of the Medical Research Council, London, and Professor Windaus of Göttingen. The 1928 Nobel Prize for chemistry was awarded to Windaus.

CHAPTER XIX

CHEMISTRY IN MEDICINE

WE have already, in the previous chapter, discussed diseases due to lack of vitamins and how such diseases can be eradicated by supplying the missing factor. We have also referred to the importance of the chemical analyses of blood and urine for purposes of clinical diagnosis. We will now show how these instances of the application of chemistry to medicine can be multiplied.

Our first topic is the ever-fascinating one of "hormones," or chemical messengers. It is not so many years ago that the English biochemists, Bayliss and Starling, isolated, in an impure form, a substance they called secretin which regulated the flow of pancreatic juice into the intestine. Since their day a number of hormones have become known; one or two have been isolated and synthesized. These hormones have this in common: they are substances which are manufactured by certain ductless glands of the body, discharged into the blood stream, and

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travel to one or more organs of the body influencing their action.

One of the best-known of these hormones is thyroxin, the active principle of the thyroid gland. Thanks to the work of Kendall, of the Mayo Clinic in Rochester, Minn., and to Harington, a London biochemist, thyroxin has been isolated and synthesized, and the synthetic product has all the activity of the thyroid gland itself. Incidentally, iodine forms part of the molecular structure of thyroxin, and this element is scarcely met with, if at all, in any other part of the body.

Thyroxin and the thyroid gland regulate the rate of oxidation or "burning" in the body. The man with too much thyroid has too rapid an oxidation within his tissues, and he is the thin, nervous type. The man with too little thyroid has a rate of combustion which is distinctly retarded, and he is apt to be slow mentally and rather fat. The addition of thyroxin to the latter, and particularly to children suffering from hypo-thyroidism, or too little thyroid, has proved a very specific cure in many instances.

It was but yesterday that Banting announced his discovery of insulin. Insulin is the hormone found

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in the pancreas (sweetbread) which has been found of such great use in the treatment of diabetics. We have not yet been able to obtain insulin in the chemically pure condition, and we are very far, therefore, from being able to make it in the laboratory; but very concentrated extracts have been obtained, and these, when injected into diabetic patients, cause the blood sugar and the sugar in the urine to decrease in amount and markedly improve the health of the patient.

Adrenaline, the active principle of one part of the adrenal glands, was isolated some years ago by Takamine, a Japanese investigator working in this country, and by Professor Abel, of Johns Hopkins; later, it, like thyroxin, was synthesized. So far, thyroxin and adrenaline are the only two hormones which can be made artificially. "Adrenaline produces," we are told, "constriction of the blood vessels, and when administered with a local anesthetic, it delays absorption, decreases toxicity, increases the duration of anesthesia, and decreases hemorrhage."

The pituitary, a gland situated at the base of the brain, contains a hormone (or hormones?) which influences stature, among other things. Too little of

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it may give rise to dwarfs and too much to giants. It also seems to be related to the entire function of sex.

Quite recently the Canadian biochemist, Collip, isolated an extract from the parathyroids—glands connecting the thyroids—which has been shown to influence the calcium metabolism of the body; and just as recently, Allen and Doisy, of St. Louis, have succeeded in obtaining an extract which apparently contains the female sex hormone. No field of chemical and biological research is being more feverishly explored than that of hormones.

We next turn our attention to “chemo-therapy,” a word coined by Ehrlich. Chemo-therapy deals with those substances which have the power to destroy germs, without appreciably affecting surrounding tissues. The question originally raised by Ehrlich was this: with a specific germ in the body, is it possible to find some chemical which, when injected, will destroy the germ without materially harming the tissues of the body?

Centuries ago the Indians in Peru hit upon the use of cinchona bark in the treatment of malaria, and in the Middle Ages mercury began to be used for

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syphilitic sufferers. The natives of Brazil have long known that ipecac is a remedy for amebic dysentery. But these were hit and miss discoveries, and little real progress could be made until, well within recent times, bacteriologists succeeded in isolating pathogenic micro-organisms, and chemists succeeded in building up synthetic organic chemistry.

Coal-tar chemistry, which had its origin in Perkin's work, and which was later developed in Germany, was at its height when Ehrlich began his researches. He became interested in African sleeping sickness, a disease brought about by trypanosomes, a group of micro-organisms. The disease was induced in mice and hundreds of chemicals were then injected in the hope of killing the parasite. A dye, trypan blue, finally proved successful, though in its application to man it fell short of expectations.

But his next attack was more successful. Turning his attention to the treatment of syphilis by the use of compounds containing arsenic, Ehrlich prepared and tried various arsenical combinations, until the 606th preparation gave him the desired result. This 606th compound came to be known as salvarsan, and began to be used by physicians in 1909. More re-

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cently, chemists in the U. S. hygienic laboratory have prepared sulpharsphenamine, a compound closely allied to salvarsan, but with the advantage over the latter that it can be more easily injected, and is of particular use in treating syphilis of the nervous system.

The treatment of African sleeping sickness, which Ehrlich tried to perfect, became possible a few years ago with the isolation of another arsenical compound known as tryparsamide. The two chemists, Jacobs and Heidelberger, of the Rockefeller Institute, first succeeded in synthesizing this compound; and it was later successfully applied in the Belgian Congo to patients suffering from this dreadful disease. The Germans have prepared a compound, known as Baeyer 205, the composition of which has not been revealed, which is said to surpass tryparsamide in its potency. Tryparsamide has also been used with some success in the treatment of cases dealing with general paralysis; here Dr. Loevenhart, of the University of Wisconsin, has been a pioneer.

The elements bismuth and antimony are closely related, chemically, to arsenic—a fact brought out very

strikingly in Mendeléeff's periodic classification of the elements. This suggested experiments in which bismuth and antimony compounds were substituted for those of arsenic in the treatment of syphilis and other closely related diseases, and here the results have been very encouraging.

The potent substance in cinchona bark which cures malaria has been found to be quinine. As is well known, mosquitoes transmit the germ to man, and while draining swamps and screening houses is part of an efficient program, the use of quinine, both as prevention and cure, cannot be omitted. Here again the Germans have placed a substance on the market, which they call plasmochin, which is said to be more efficient than quinine, but the last word has not yet been said.

Among the diseases due to bacteria (plant forms) rather than to protozoa (animal organisms)—which is what we have been discussing so far—is leprosy, a disease which seems to have made its appearance quite early in the history of man. For its treatment, chaulmoogra oil, obtained from certain tropical trees, has been found of use, but the work of Dr. Adams,

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of the University of Illinois, in isolating the active constituents in the oil, promises much more for the future.

The attempts to cure tuberculosis with sanocrysin, a gold compound, and pneumonia with optochin (a compound related to quinine), have not been successful, judging by the majority of the results, though the chemo-therapist remains confident that eventually some chemicals will be discovered to answer the requirements. But one cannot pass over the work of Carrel and Dakin, the Franco-American and the Anglo-American workers, respectively, who, with their Dakin's solution, saved the lives of countless numbers of wounded in the late war. The solution, in its various modifications, contained chlorine in one form or another, and draining wounds with such a preparation often destroyed the invading micro-organisms without injuring the tissues. This chlorine, which was the first poison gas used, could, you see, be put to a much more humane use. But that is the story of practically all poisons.

The applications of chemistry to medicine are even more manifold than the science of chemo-therapy would lead us to believe. In the field of anesthetics

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the chemist has supplied ether, chloroform and nitrous oxide (Davy's "laughing gas"), and, within the last two or three years, Dr. Luckhardt, of the University of Chicago, has introduced ethylene, which, in conjunction with oxygen, looks as if it is going to supplant all other general anesthetics.

Local anesthetics date back, in a sense, to the sixteenth century, when Spaniards in Peru noticed that the Indians chewed a plant, coca erythroxylon, to avoid fatigue; but it was not until 1855 that the alkaloid, cocaine, was obtained from it, and it was not until 1884 that Koller, a New York surgeon, showed how cocaine could be used in surgery of the eye. Many chemists—among them Wilstätter—worked on the chemical constitution of cocaine; and when that problem was finally solved, chemists working in conjunction with physicians, set out to find which particular part of the cocaine molecule exhibited anesthetic properties. When this problem was solved, the chemist embarked on the new problem of creating a compound in the laboratory which would surpass Nature's product; and he produced novocaine (or procaine, as it is sometimes called), a substance which is "much less toxic than cocaine, stable

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in solution, less expensive to manufacture, and does not lead to habit formation." The committee on synthetic drugs of the National Research Council in Washington has declared novocaine to be "one of the three most valuable and indispensable drugs." Butyn, closely allied to novocaine, chemically, has also come into use, because though more toxic than novocaine, it produces anesthesia more quickly and, like novocaine, is not habit-forming.

Among hypnotics, or sleep-producing substances, chloral was the first synthetic product used, but the discovery of veronal (or barbital) in 1903, when Fischer first prepared it, put chloral on the back shelves. Veronal, a compound related, chemically, to urea, "can be depended upon to act promptly to produce a deep, restful sleep, and seems not unduly toxic when moderate quantities are used." Luminal, a close chemical neighbor of veronal, is of value in the treatment, more particularly, of nervous disorders.

The chemist has investigated digitalis and digitalis-like bodies to determine what type of molecular structure makes such substances so valuable in the treatment of heart afflictions; and much has been gained, though much remains to be solved. To the

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digitalis group belong such preparations as digitoxin, ouabain, strophanthin, etc.

In relation to high blood pressure, the chemist has isolated a substance tyramine, closely related to adrenaline, which causes an increase in blood pressure when injected into animals; and tyramine, and several other related substances are at present suspected of being involved in the development of high blood pressure.

One could fill many more pages on the contribution of the chemist to medicine: the introduction of the salts of phenolphthalein to estimate the functional capacities of the liver and the kidney; the investigation of lead tetraethyl (the "anti-knock" in gasoline) and other industrial poisons; the chemical analysis of milk, butter, flour, etc., to detect adulterations; the chemical analysis of water to determine whether it is fit for drinking purposes, and the methods dealing with water purification; the analysis of various so-called medicines which flood the market, to expose those which are harmful or fraudulent, and so on. But enough has been said, we believe, to justify the claim of Paracelsus of old, when he declared that medicine without chemistry is neither medicine nor science.

CHAPTER XX

CHEMISTRY IN INDUSTRY—COAL, PETROLEUM AND IRON

SO far we have made little attempt to dwell upon the relation of chemistry to industry. It is true that we devoted some space to Perkin's discovery of mauve and its consequences in building up the dye industry; it is also true that we described Haber's method of nitrogen fixation and its relation to agricultural production; but the emphasis in the one case was one of history—how Perkin obtained the first coal-tar dye; and the emphasis in the other related to a scientific principle enunciated by Le Chatelier. Here, in this chapter, it will be our object to show that most of the basic industries, and many other industries, in this country and abroad, involve chemical principles, and that progress in industry is dependent upon the intelligent application of such principles.

Coal, oil, iron and steel represent the nucleus, as it were, around which all industry is built. We shall take these up in turn. Let us begin with coal. Coal

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as such is a fuel; it can be made to burn and give heat. But the contribution of the chemist has been to show that by first distilling coal, many valuable by-products are obtained which would otherwise be lost. If you put coal in a retort and heat it strongly, there pass over various volatile products, such as coal-tar, ammonia and coal gas, and coke remains in the retort. Chemists in the last hundred years have shown how such products can be isolated and utilized. As I write these lines, there comes a report from Pittsburgh, "the largest producer in the world of coke and coking by-products," which informs us that the ovens in that city alone are turning out 16,500,000 tons of coke, 190,000,000,000 cubic feet of gas, 235,000,000 gallons of tar, 50,000,000 gallons of fuel oils, and 250,000 tons of ammonium sulphate, having an aggregate value of more than \$100,000,000. The industry has grown to such an extent that whereas 240,000,000 tons of coal were mined in the United States in 1900, the amount increased to 600,000,000 tons in 1926.

The coke can be used as a fuel, but it is even more important in the manufacture of iron, which we shall take up presently. The tar is none other than the

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“dirty, evil-smelling material” out of which Perkin obtained the first coal-tar dye, and from which are made the thousands of dyes and the hundreds of drugs which flood the market to-day. It should be emphasized again that these dyes and drugs are not obtained directly from the tar, but that the tar is first distilled, yielding such substances as benzol, toluol, naphthalene and anthracene; and that with these as starting material, the various dyes and drugs are made—processes which in every instance have been worked out by the chemist. And again it should be pointed out that the manufacture of dyes and drugs has led to the development of industries closely related to it. For example, in the course of manufacturing a dye, one of the commonest operations is a process known as nitration, which involves the use of nitric and sulphuric acids. Not only were the manufacturers called upon to supply more of these acids, but an impetus was given for improving methods of production; here, again, the chemist was consulted.

The ammonia, another product, being a gas, is converted into a more stable salt, usually ammonium sulphate; and this can be used as a fertilizer. Ammonia and ammonium sulphate contain nitrogen in

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a form which can be utilized by plants, and nitrogen, as has already been pointed out in a preceding chapter, is an element that is absolutely essential to plant life. We have already seen how ammonia is now also obtained synthetically by the Haber process; and as fertilizers are needed in ever-increasing quantities, the Haber method is of great value in supplying deficiencies.

While we are on the subject of fertilizers, let us point out that the fertilizers as supplied to the farmer contain potash and phosphorus salts as well as nitrogen salts. The potash salts are obtained almost exclusively from the Stassfurt mines in Germany; though by the intelligent application of a chemical principle, known as the phase rule, and developed by the American chemist, Willard Gibbs, potash is now being profitably extracted in California. Phosphorus salts are obtained from deposits of phosphate rock found in various parts of the country. Since phosphate rock as such is a highly insoluble salt, and since, therefore, it would be but slowly absorbed, it is converted into a more soluble form known as superphosphate by treatment with sulphuric acid. The discovery of this process has led to an increased pro-

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duction of sulphuric acid, and since the starting point for the manufacture of sulphuric acid is sulphur, the sulphur mines in Louisiana have been turning out more and more sulphur to meet the demand.

We next turn to coal gas, another product of the distillation of coal. We are all familiar with the fact that it is used in our homes and in the industries as a fuel and for lighting purposes. Very often this coal gas is mixed with "water gas," a product obtained by passing steam over strongly heated coke, and which is very largely a mixture of carbon monoxide and hydrogen, gases which burn and have a high fuel value. Out of coke, or out of coal with a high content of ash—which would make such a coal unsuitable for other purposes—another fuel, known as producer gas, is also manufactured. This producer gas is made by passing air over the heated coal or coke, and is a very common fuel in the industries. It consists very largely of carbon monoxide and nitrogen; and while the latter does not burn and therefore acts merely as a diluent, and while, therefore, the heat value of producer gas is less than that of water gas, producer gas is cheaper to manufacture than water gas. Again, the work of the chemists.

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We can now turn to the one fuel that rivals coal, petroleum. It seems almost incredible to believe that the first oil well in this country was drilled by Colonel Drake as recently as the middle of the last century, and that before that time the Indians used the small quantities of oil that would appear at the surface of springs as a sort of universal remedy for all kinds of ills. Already in 1900 this country produced nearly three thousand million gallons of petroleum, and in 1926 the amount had risen nearly eightfold. Since these deposits are not replaceable, since oil—or coal—cannot be made to grow the way trees do, no wonder that our conservation experts are alarmed; but such an alarm acts as an accelerating agent on the chemist, and he solves the difficulty before the catastrophe overtakes us. We shall see presently what his solution is.

Silliman, famous at Yale as chemist and teacher, found that by heating petroleum and collecting and condensing the gases that were given off, certain fractions of the condensed gases—the kerosene of to-day—could be used for illuminating purposes. This was a capital discovery, for up to this time the illuminating oils consisted of expensive animal and

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vegetable fats. A further step forward was made when this illuminating oil was first submitted to a purification process by treatment with oil of vitriol and alkali before being sent to the market. Until about 1900 little use was made of the low- and high-boiling fractions, containing naphtha and tar respectively. Only those fractions boiling between 212 and 500 degrees received much attention. This means that millions of gallons of gasoline and pitch were lost.

In the meantime oil had been discovered outside of Pennsylvania near Lima, Ohio. This oil contained large quantities of sulphur which made its use difficult. It remained for Frasch to discover that this impurity, particularly obnoxious because it gave the odor of burning brimstone when the oil was burned, could be eliminated by heating the oil with oxide of copper.

The discovery of petroleum in Ohio occurred in 1885. Until then chemists in the petroleum industry were conspicuous by their absence. But the sulphur problem proved too much for the "practical" man and he was forced to appeal to the scientist.

About this time the Standard Oil Company of Indiana, much ahead of its competitors in mapping out

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revolutionary programs, engaged the services of William M. Burton, one of Ira Remsen's products from Johns Hopkins. Burton's entrance upon the scene marks a new era in the petroleum industry. From the very first, Burton gave particular attention to the preparation and utilization of the naphtha, or low-boiling products. The invention of the internal combustion engine, and, later still, the introduction of the automobile, gave the naphtha and the gasoline fractions an importance which they had hitherto lacked. Burton knew that by distilling under pressure the fractions with high-boiling points, many of the complex substances present could be broken up into simpler units with lower boiling points. This had actually been done in the laboratory. But to apply such a laboratory finding to the operations as carried out in a huge technical works was quite another matter. Experienced refiners and able engineers strongly advised the company against large-scale operations. But Burton, who had originally suggested the scheme, insisted that the idea was feasible.

A still with a capacity of 6,000 gallons was built and large-scale operations were started. From the very first little difficulty was found in obtaining the

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lower boiling point products by heating the higher boiling point ones under pressure. But what did give trouble arose from leaks that developed in the still. With each leak a fire would break out which, in extent, was directly proportional to the size of the leak. The leaks and the fires began to dampen even Burton's enthusiasm. But nature came to the rescue, for by continued distillations, enough carbon from the oil deposited to stop all leaks. From then on it was smooth sailing. Stills were added year by year, until to-day the company has some 500 of them. The production of the invaluable gasoline was multiplied fivefold, and, incidentally, the residues left from the distillation proved as excellent samples of asphalt as any that had ever been mined in the Island of Trinidad. To-day an average of 4,000,000 barrels of gasoline and naphtha are produced every year by the use of the Burton still alone.

Quite recently, Dr. Bergius, a German chemist, has pointed the way to solving the petroleum shortage. He makes synthetic gasoline by heating hydrogen and finely powdered coal of low-grade quality at a fairly high temperature and under a very high pressure. From the "petroleum" so obtained, "gaso-

line" is recovered by the usual distillation methods.

In the development of this process, the physical chemist, the industrial chemist and the organic chemist have all played a part. Coal, though largely made up of carbon, also contains some hydrogen, and by adding more hydrogen to the coal, the carbon and hydrogen combine to form hydrocarbons of a type such as is usually met with in petroleum. But while the theory underlying the process is simple enough, the technical difficulties involved are even greater than in the Haber process for the manufacture of ammonia. But just as in the Haber process, these difficulties were eventually overcome by the application of the Le Chatelier principle, to which reference has been made in a former chapter. One cannot emphasize too often how every step in industrial development is dependent upon abstract scientific research—the kind of research that does not at first glance seem to have the remotest connection with matters practical.

And now we shall turn to another basic industry in which the hand of the chemist is seen at every turn—iron and steel. The manufacture of iron goes back to the remotest antiquity, but improvements

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in its manufacture, and methods for producing steel, are the accomplishments of many chemists in the last two or three generations. First let us understand the chemistry of the process involved. The iron ore is mined; it is found in nature, and is essentially iron oxide, a combination of iron with oxygen. The chemist will tell you, and your experience will confirm the statement, that the metal iron, unlike gold or platinum, is not very resistant to the action of air, that it easily "rusts," and that when it does rust it combines, among other things, with the oxygen of the air to form iron oxide. It is not surprising, therefore, that iron, unlike gold, is not found in the metallic state. But nature does provide us with iron oxide, and the problem of the chemist is to convert the iron oxide back again to iron. In order to do so, he applies the process of reduction, whereby a substance such as carbon is used which, under suitable conditions, can drag the oxygen away from the iron oxide and leave the iron behind. We can summarize this reaction in the form of a chemical equation, which is the favorite language of the chemist: iron oxide plus carbon yields iron plus carbon monoxide. Since coke is very largely a form of carbon, and since

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it is relatively cheap, coke is usually employed. You now see why coke, which is obtained as a residue in the course of the distillation of coal, is of such value in the iron and steel industry.

Since the iron ore found in nature is not very pure iron oxide, but contains appreciable quantities of phosphorus, silicon and other impurities, which if not removed would lessen the quality of the iron, a flux, usually limestone, is added to get rid of such impurities. So that the "charge," or starting materials, consists of iron ore, coke and flux. This mixture is put into a big blast furnace, heated very strongly, and in due time "cast" or "pig" iron can be withdrawn from the furnace. Out of fifty million tons of iron ore, which go into three hundred blast furnaces, some twenty-five million tons of pig iron are produced.

This cast iron can be and is used for castings (ranges, pipes, radiators), columns, engine foundations, etc., but since it is very brittle and withstands very little stress, its use is, in reality, quite limited. As a matter of fact more than 70 per cent of cast iron is converted into the infinitely more valuable steel.

Chemically speaking, the essential difference be-

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tween cast iron and steel is that the former contains more carbon. A typical analysis shows cast iron to contain 93 per cent of iron, 4 per cent of carbon, with the rest divided among silicon, sulphur, phosphorus and manganese, whereas steel contains 99 per cent iron and one-half of one per cent carbon. The amazing difference in properties between iron and steel hinges upon the presence or absence of a small quantity of carbon. We shall see pretty soon that this is no unique instance of chemical (and physical) properties being profoundly influenced by the presence of small quantities of various elements.

In the fifties of the last century, Bessemer, an English chemical engineer, developed a process for making steel which revolutionized the industry. In principle, it consists of passing a current of air through molten pig iron, whereby most of the impurities, including the carbon, are removed. As too much carbon is removed, and as a certain small quantity is necessary to give steel its peculiar qualities, a calculated amount of carbon is then added. The open-hearth process for making steel, which came later, has been an improvement on the Bessemer method, and a superior grade of steel is here obtained.

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“Steel has a range of properties,” we are told, “which is unequaled by any other substance. It can be made hard or soft, malleable or brittle. It can be made like cast iron or wrought iron, and it can assume the properties of many other substances. It can be permanently magnetized, and it has, in the highest degree, the valuable property called elasticity. These properties of steel make possible our present-day civilization, with its railways, steamships, bridges, skyscrapers, etc.”

We spoke of the remarkable properties given to iron by the addition of a small quantity of carbon. We have seen that the presence of some 4 per cent of carbon in the iron gives us pig iron, and that when much of this carbon is removed, and only about one-half of one per cent is left, we get steel. If we continue removing even more carbon, so that only about one-tenth of one per cent is left, we get wrought iron, a form of iron which though far more limited in its use than steel, still finds use in some industries, such as those dealing with hardware (nails, bolts, hinges, etc.), various agricultural implements, electro-magnets for dynamos, etc. To remove every trace of carbon from iron is well-nigh impossible, and

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when the chemist needs pure iron, he prepares it in a totally different manner.

But we are not yet through with steel. Just as a small quantity of carbon endows iron with certain properties, so the addition of small quantities of other elements to steel gives the latter certain added advantages. Among such "alloy steels" are nickel steel, which is harder and tougher than ordinary steel and which is used for rail curves, bridge steel, etc.; manganese steel, used for rock crushers, railroad switches, safes, etc.; and chrome steel, used for armor plate, crushing machinery, automobile gears, and for making stainless and rustproof steel. There are also silicon, vanadium, tungsten and molybdenum steels, each variety having certain virtues and certain limitations.

Iron undergoes oxidation so easily when exposed to air, it rusts, as we usually put it, that various methods have been employed to prevent such rusting, though no one method seems perfect. Sometimes painting is employed, sometimes the iron is coated with such metals as zinc, tin or nickel, sometimes an enamel is put on, and so on. But the rusting of iron still remains a problem.

CHAPTER XXI

CHEMISTRY IN INDUSTRY—CELLULOSE, ETC.

THE cells of plants are surrounded with cellulose. Cellulose is the most characteristic, as well as the most common, plant constituent. Around this substance, chemical industries have been built which are assuming wider and wider proportions.

Cotton, linen, hemp and paper are largely cellulose. Their different properties depend largely upon the physical make-up of this cellulose molecule; and the various attempts to convert one form into the other are attempts made to change the physical make-up.

In the manufacture of paper from wood pulp, say, the first part of the process is definitely chemical in its nature, for here we wish to get rid of resinous materials and other impurities. This is commonly accomplished by what is known as the sulphite process, an invention due to Benjamin Tilghman, of Philadelphia. In this the broken pieces of wood are boiled with calcium sulphite. The rest of the process is

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largely mechanical, involving thorough mixing of the pulp, and eventual pressing and drying. "Sizing," usually with glue, gives a smooth finish to paper, though, of course, this is omitted in the making of blotting paper or paper towels.

The original observations of the French scientist, Chardonnet, who spent his leisure time watching the silkworm build its silk, led to the development of the "artificial silk" industry, or, as it is now more commonly called, the rayon industry. It should be made clear at this point that rayon, exhibiting most of the qualities of silk, differs radically from silk in chemical composition. Essentially rayon is a variety of cellulose. Although rayon and cotton are very similar chemically, yet in many other properties, particularly those which appeal to men and women, rayon and silk are far more closely allied. In one process of manufacturing rayon, the cellulose is converted into one of its salts (such as the acetate or nitrate), then squeezed through small openings to produce fibers and finally spun into threads. Statistics tell us that in 1900 but a few thousand pounds of rayon were produced, whereas twenty-five years later the production rose to 200,000,000 pounds.

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When cellulose is treated with nitric acid it will combine with the acid in one of several ways, depending upon the amount present and other conditions. The cellulose nitrates so produced may either form very powerful explosives, or else they can be used for the manufacture of celluloid and various lacquers and plastics.

The explosive cellulose nitrate is known as nitro-cellulose or guncotton. Modern explosives are all nitro compounds—compounds treated with nitric acid. For example, nitroglycerine is glycerine treated with nitric acid. It was Nobel who discovered that nitroglycerine could be handled much more safely by adding some inert substance, such as infusorial earth, starch or sawdust; in this way we get what is called dynamite. Nobel made much money with his dynamite and he founded the Nobel Prizes, given yearly to eminent scientists and others throughout the world.

Picric acid, another explosive, is made by treating carbolic acid with nitric acid, and trinitrotoluol, the famous T.N.T., is made by the action of nitric acid on toluol. As in all of these operations a certain amount of water is produced, which, if allowed to remain, would spoil the product, concentrated sul-

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phuric acid is always added, for this acid acts as a dehydrating agent, extracting the water and combining with it.

The application of electricity to chemical processes has led to many vast industries. This application takes one of two forms: the use of electricity as a chemical agent, and its use as a source of great heat. Oxygen and hydrogen are now made in large quantities by the electrolysis of water—passing an electric current through water. The oxygen is used in the oxyacetylene blowpipe or as a source of respiration for airmen, miners, pneumonia sufferers, etc. The hydrogen may be used in the oxyhydrogen blowpipe, for the making of lard, for the manufacture of ammonia by the Haber process, etc.

Another industry employing electricity as a chemical agent is the lye industry, which is carried on at Niagara Falls. Here a current of electricity is passed through a solution of brine (salt dissolved in water), and by using an apparatus which was originally devised by the American chemist, Castner, and since modified, caustic soda (lye), chlorine and hydrogen are all produced at the same time. The caustic soda, among other things, is used for making soap, and

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the chlorine finds wide use as a bleaching and a disinfecting agent.

Hall, in 1886, while a student at Oberlin College, hit upon a method of preparing aluminum cheaply, and the price dropped from \$100 a pound to 25 cents a pound! His process also makes use of electricity. Under appropriate conditions, bauxite, essentially aluminum oxide, is decomposed by the electric current into aluminum and oxygen. Wöhler first isolated this metal, Hall first produced it cheaply enough so that it could find general application, and, as everybody knows, Mellon, our Secretary of the Treasury, is the King of Aluminum!

The processes of electroplating and electrotyping illustrate the application of chemistry to industry. Nickel, silver, gold and other metals are used for electroplating. The article so treated is made more durable and more attractive in appearance. In principle the process is simplicity itself. The object to be plated is made the cathode, and, if silver plating is desired, the anode consists of a bar of silver, with the solution or "bath" consisting of some silver salt. When the current is passed through such a system, some of the silver will become deposited on the

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cathode. In electrotyping an impression in wax is made of the print or "type"; it is dusted with graphite and then hung on the cathode, the anode being a copper bar and the solution consisting of copper sulphate. Copper deposits on the graphite, and this forms the "nucleus" of the plate with which the printing is done.

Now electricity can act not only as a chemical agent, but also as a source of very great heat. The use of electricity in this direction was first systematically investigated by the French chemist, Moissan, who was a professor of chemistry at the Sorbonne, and who was interested in the field of pure research only. Despite the fact that giant industries have arisen as a result of his researches, and untold millions have been made as a consequence, Moissan died a poor man.

The simplest form of Moissan's electric arc furnace consists of "two blocks of lime with central cavity for the crucible containing the materials to be used and horizontal cavities for the graphite electrodes. The electrodes are first made to touch one another, the current is turned on, and the electrodes are gradually parted, when an arc is formed between

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the two; and this is the source of the intense heat." Here, then, electricity is not the active chemical agent; it merely supplies enough heat so that reactions may be made to take place. By the use of such a furnace, and various modifications of it, we manufacture calcium carbide, carborundum and graphite. The calcium carbide is made by heating coke and quicklime at this high temperature and is used for the preparation of acetylene and for the preparation of calcium cyanamide, a valuable fertilizer. Heating silica and coke in the electric furnace gives us carborundum, first made by the American chemist, Acheson, which is used as an abrasive, because it is almost as "hard" as the diamond. Graphite is found in nature, but it is now also very largely made by heating coke in the electric furnace. Coke is an amorphous variety of carbon—a variety which has no crystalline shape. Graphite, on the other hand, is a crystalline variety of the same element. Intense heat, as we see, converts one form into another. Diamond is also a crystalline variety of carbon, and of course attempts have been made to convert either coke or graphite into their more valuable relative, but with little success, so far. Moissan, in one of his experiments, did

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get what seemed to be microscopic diamonds, but even his work has since been questioned.

Very high temperatures are also needed for welding purposes and for cutting manholes in steel plates. Here the oxyhydrogen, and even more, the oxy-acetylene blowpipe, has been used. The chemist first showed that the burning of a mixture of oxygen and hydrogen produces a very hot flame, and that even a hotter flame—comparable to that obtained in the electric arc—is obtained when a mixture of oxygen and acetylene is burned. Langmuir, that genius of the General Electric Co., who has recently been elected president of the American Chemical Society, has obtained tremendously hot flames, admirably suited for welding, by using atomic hydrogen. "Hydrogen gas is first passed over an electric arc. The heat of the arc breaks up the hydrogen molecules into hydrogen atoms. These combine again a short distance beyond the arc into molecules of the gas, and in so doing liberate an enormous amount of heat. Fluxes are not needed here, and surface oxidation is prevented, since any oxides formed are immediately reduced to metal by the hydrogen."

CHAPTER XXII

CHEMISTRY IN INDUSTRY—PHOTOGRAPHY, ETC.

EVERY one is familiar with that remarkable “photo-chemical” action, whereby sugar and starch are formed in the leaves of plants. Here light is the activating agent; it is a chemical agent. The more careful analysis of light by physicists has made it clear that light covering the range from the infra-red to the ultra-violet region shows varying properties dependent upon differences in wave length; and the chemists, in turn, have shown that the most active rays, chemically, are those in the ultra-violet region. We have already alluded to light in its curative action in rickets; we need merely mention here that it is the ultra-violet rays which show this action in a most marked degree. The conversion of ergosterol into vitamin D by the action of light is a conversion due to ultra-violet rays—a chemical action involving subtle chemical changes. *Subtle*

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chemical changes is an appropriate phrase to be used in connection with light and chemical action.

The process of photography is an excellent illustration of the action of light, and to this process chemists have made many valuable contributions. Photography depends upon the sensitivity to light of silver salts. The alchemists noticed that silver salts "turn dark" when exposed, but the Frenchman, Daguerre, working in 1839, first showed how this property could be made use of in photography.

The chemical principles underlying the process of photography are simple. The plate contains silver bromide, and that part of it exposed to light is partially reduced to the silver condition. This constitutes the "exposure." "Development," the next operation, consists of completing the reduction induced by light. For this purpose, some "reducing agent" (pyrogallol or hydroquinone) is used. We now have a plate which is partly dark, due to the production of silver (silver in a finely divided condition is black), and partly light in those regions containing silver bromide—in those portions, in other words, where light did not penetrate. The "fixing," the third step in the making of a photographic film, is the removal of the unde-

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composed silver bromide by immersing the plate in "hypo," chemically known as sodium thiosulphate, in which the silver bromide is soluble. We now get the "negative" of our picture—"negative" because the colors are reversed. "A light-colored object, reflecting much violet light, affects the silver bromide very much, and so produces a heavy deposit of silver, which is black. A dark object does not reflect much light, and so the silver bromide is unaffected, and ultimately washed off by 'hypo,' leaving the transparent film." "Printing," the fourth step, is the production of the "positive." Here a silver bromide paper is placed under the negative and exposed to light. Where there is no silver on the negative, and therefore an area devoid of color, the corresponding area on the positive becomes dark, and vice versa.

"Blue-printing" is another process dependent upon the action of light, only here instead of silver salts we use iron salts. Iron, in what is known as the ferric condition, is reduced to the ferrous condition when exposed to the sun's rays and in the presence of certain "reducing agents." Ferrous salts, in turn, form a blue product (hence blue-printing) when mixed with potassium ferricyanide, whereas ferric salts do

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not, so that that part of the paper which has not been "exposed"—covered by the object to be blue-printed—remains in the ferric condition and is unaffected by the potassium ferricyanide.

If certain details of photography and blue-printing have been discussed, it was only because our object was to illustrate how intimately bound up these industries are with the science of chemistry.

The action of light, the action of oxygen, the action of moisture, all produce chemical effects, and while such action is sometimes desirable, at other times it is not. We have seen how iron rusts when exposed to the air. This illustrates a chemical reaction, but we would give very much indeed to prevent such a reaction. We have seen that one method of protection—not a permanent one, it is true—is to apply a coat of paint. But as a matter of fact, iron is not the only substance that is chemically affected when exposed, many other substances are, too; and in order to protect them, a vast industry has been developed—the paint industry. The essential part of a paint is the liquid, which may be, and often is, linseed oil, and the suspended solid, which may consist of white lead mixed with an appropriate pigment.

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It is only years of chemical research by men like Toch and others which have made it possible to produce the most varied paints for the most varied conditions—from painting a house to painting a picture.

When the Germans reached Brussels in the early part of the Great War, they called upon Solvay to pay a very heavy fine. Solvay was a prominent Belgian citizen. He had made money by devising and developing the "Solvay" process for making baking soda and washing soda, and his method is on the road to replacing the older Le Blanc process. Washing soda, as its name implies, is used for washing purposes, and when an alkali is needed which is milder than lye or caustic soda. Its relation to alkalies is very much the relation of sulphuric acid to acids. Baking soda, as its name implies, is used in baking as a constituent of baking powder. Its other name, "bicarbonate of soda," suggests its medicinal use.

Solvay discovered that when ammonia and carbon dioxide are pumped into a solution of brine, baking soda is formed. If necessary, the baking soda is heated and converted to washing soda. Since the raw materials are cheap, since the apparatus required is comparatively inexpensive, and since the "by-products"

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are used over again, the Solvay process has proved itself one of the most successful among chemical processes.

The by-products obtained in the course of the manufacture of baking and washing sodas are ammonium chloride, from which ammonia can be recovered, and carbon dioxide. Both the ammonia and the carbon dioxide can be used for the preparation of a fresh batch of baking and washing sodas.

The story is related how during the World War kitchen scraps in army kitchens were collected, the fat separated and converted into soap and glycerine. The soap was sent to the soldiers, to whom it was most welcome, and the glycerine found its way back into a factory, where it was converted into nitroglycerine, an explosive. Out of the discard from the table they obtained a cleanser and an explosive.

Such, in principle, is the method of making soap. The fat or oil is boiled with caustic soda and the soap is separated from the glycerine by the addition of salt, whereby the soap comes to the surface and can be ladled off. The caustic soda (sodium hydroxide) is an alkali, like washing soda, but much more powerful or caustic. You will remember that it is prepared by the

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electrolysis of a brine solution. To salt and to fat we owe soap.

A milder alkali than caustic soda is "slaked lime," which in solution is called lime water, and in suspension milk of lime. This slaked lime is made by mixing "quicklime" with water; and quicklime, in turn, is obtained by heating limestone, which is found in nature. The quicklime, or calcium oxide, you may remember, can be mixed with coke and heated in an electric furnace to yield calcium carbide, from which acetylene or cyanamide (a fertilizer) can be obtained. Or the quicklime may be mixed with water and sand to form the mortar used in the building industry.

The heating of limestone and clay produces a "hydraulic mortar," a mortar that "sets" under water; and it is usually known as cement. Concrete is cement mixed with sand and gravel. Cement and concrete, even more than mortar, are used in the building trades. Their value lies in their property of hardening in the course of time.

A compound related to mortar and cement, and also possessing the property of hardening on standing, is gypsum, a natural mineral which, when heated,

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produces plaster of paris. When the plaster of paris is mixed with water, it not only hardens, but expands slightly; and it is this latter property which makes it so valuable in making molds and casts.

The "hard" waters which corrode boilers and do not readily produce a lather with soap, often contain compounds related to limestone and gypsum. This entails a "water-softening" process, often of huge dimensions.

Alkalies are also used in the manufacture of glass. The commonest variety is made by heating a mixture of sand, limestone and sodium carbonate (washing soda). If in the place of sodium carbonate we use potassium carbonate, a "harder" and less fusible glass is obtained. The famous Pyrex glassware, developed in this country during the World War because Jena glass could not be imported, contains boron as well as silicon compounds.

CHAPTER XXIII

CHEMISTRY IN INDUSTRY—CATALYSIS

WE have far from exhausted the applications of chemistry to industry, nor would it be possible to do so in a book of this scope. What we are far more interested in doing is to select several leading industries in which the principles of the science of chemistry find ample and simple illustration. With that in mind, we now refer to a phase of the science which is receiving very much attention, and which is called catalysis.

We have referred to this catalysis once before in connection with the Haber synthesis of ammonia. The subject of catalysis is so broad a field, and it touches so many growing industries, that one is justified in referring to it at some length.

The "catalytic agent" is the substance which influences a chemical reaction without itself undergoing any permanent change. Usually it accelerates a chemical reaction, sometimes it retards it. In most cases we

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want chemical reactions accelerated; in only a few instances do we want reactions retarded.

The subject of catalysis is bound up not only with chemical industry, but with some of the most beautiful abstract chemical research of the present generation; its importance lies in the field of biology no less than it does in chemistry.

The subject of catalysis goes back to studies dealing with fermentation, concerning which different theories have been advanced with each succeeding century. Lavoisier, Liebig and Pasteur busied themselves with this problem. Pasteur assumed that fermentations are the result of the activity and the multiplication of living organisms. Sugar is converted to alcohol and carbon dioxide by yeast, and the yeast cells, in turn, grow and multiply. It was very much later—in 1896, as a matter of fact—that Buchner, a German biochemist, published the results of experiments which tended to modify the views advanced by Pasteur. Buchner subjected yeast cells to very high pressure, filtered the product and collected some of the filtrate, or liquid which passed through the filter. He found that this liquid still retained the property of converting sugar into alcohol. Now you

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must remember that the enormous pressure to which the yeast cells were submitted completely destroyed all "life" within them, so that one is forced to the conclusion that the "something" in yeast which brings about the fermentation is a something apart from the living yeast cell itself.

As a matter of fact, we are aware today that yeast and many other cells, whether plant or animal, have the ability to manufacture this something to which the name ferment or enzyme has been given. Enzymes have this in common: they are all catalysts which are produced as a result of cellular activity, but they are not living things themselves. Enzymes differ in that they show "specificity" in their action: some, like zymase, convert sugar into alcohol; others, like ptyalin, convert starch into sugar; others again, like pepsin, convert proteins into simpler bodies. In fact, all the complex chemical reactions in the animal and the vegetable kingdoms, whether involving analysis or synthesis, are intimately bound up with the action of enzymes.

Enzymes, we said, are catalysts. This means, in the first place, that a comparatively small amount of the enzyme is needed for the reaction, and in

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the second place, that the enzyme is not used up in the reaction. Just how they influence chemical reactions is still very much of a mystery.

While it is true that enzymes are catalysts, we can have catalysts which are not enzymes; we can have substances showing catalytic action which are not necessarily produced as a result of cellular activity. In fact, cellular activity need have nothing at all to do with it, and such catalysts may be typical examples of inorganic substances. We have, at present, no way of telling which particular substance will act as a catalytic agent in any given process other than by trying it out. It is still largely a hit and miss proposition.

An early case of catalytic action was observed by the British investigators, Dixon and Baker, who showed that many of the common chemical reactions fail to take place *in the absence of all water*. Traces of water, at least, were necessary. Such a common reaction as the combination of oxygen and hydrogen, for example, to form water, fails completely in the absence of moisture. Even the most chemically active element we know, fluorine, becomes quite inert in a

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moisture-free atmosphere. Water here acts as a catalyst. Just how it acts is problematical.

And now we must pass on to show that catalysts have great value in the field of industry. We shall select a few examples more or less at random.

We have had occasion a number of times to refer to sulphuric acid. This "oil of vitriol" is perhaps the king of chemicals, for it is certainly used more extensively than any other compound. We need it to purify gasoline; we need it to prepare fertilizers, to make explosives, to manufacture dyes, to clean metals, to prepare other acids. Much of the sulphuric acid is now largely made by a catalytic process. Sulphur is burned to sulphur dioxide, and this, in turn, is made to combine with more oxygen to form sulphur trioxide. The sulphur trioxide when mixed with water forms sulphuric acid, though in actual practice this process is somewhat modified. It is in the conversion of sulphur dioxide to sulphur trioxide that the catalytic agent comes into play. For quite a number of years platinum has been the catalytic agent used. Without the presence of platinum very little sulphur trioxide is formed, but in its presence large

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quantities are readily obtained. Despite the high cost of platinum, the process is a commercial success, because it can be used over and over again, being a catalytic agent, and therefore not being used up in the reaction. However, extraordinary precautions have to be taken not to introduce impurities into the platinum, otherwise its efficiency is very quickly decreased. To avoid the introduction of such impurities, the sulphur dioxide and oxygen are first very carefully purified; and this is a very important phase of the operations.

Since effective chemical reactivity depends, among other things, on intimate chemical contact of the reacting substances, the platinum used is always in a finely divided condition, for in this way the surface is very much increased, and increased opportunities are given for the oxygen and sulphur dioxide molecules to come in contact with the finely divided particles of the metal.

Very recent research by the Vanadium Corporation of America holds out the hope that the oxide of vanadium may soon be used in the place of platinum.

A maximum of success in this operation, however, is obtained not only by the use of an appropriate

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catalytic agent, but by the employment of suitable temperatures and pressures—factors discussed previously under the Le Chatelier principle.

Nitric acid, used in the production of explosives, dyes, rayon, etc., can also be made by using platinum as a catalyst. Here ammonia and oxygen (or air) are passed through a tube containing the platinum, and heated to about 700 degrees centigrade. This has already been referred to as the Ostwald process, for it was first developed by Professor Ostwald of Leipzig. "This process has been developed to such a degree that nitric acid can now be manufactured from ammonia for \$30 less per ton than it can be made from Chilean nitrate (which sells around 2 cents a pound)." For the older method of making nitric acid, still extensively practiced, is to distill a mixture of Chilean nitrate and sulphuric acid.

The ammonia used in the above process—and also used for the manufacture of fertilizers, in refrigeration, in the manufacture of washing and baking sodas—is, of course, made by the Haber process, in the course of which nitrogen and hydrogen are passed through a tube containing some iron compound which is strongly heated. This "iron compound," the exact

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chemical composition of which is not known, is the catalyst.

The French chemist, Sabatier, who began his work in 1897, first showed how hydrogen can be made to combine with certain organic compounds, provided nickel were present. The nickel is the catalytic agent. This piece of pure research has since been put to use in the industries in processes dealing with the "hydrogenation" of oils. Oils otherwise unfit for food can, in many instances, be made to react with hydrogen, in the presence of nickel, and yield various lard substitutes.

Wood alcohol, or "methanol," the common poison in ordinary alcohol, which finds extensive use in the paint and varnish industries, has long been made by the distillation of wood; but quite recently the Germans have placed synthetic methanol on the market, and what is even more to the point, the synthetic methanol, in no way different from that obtained by the distillation of wood, is cheaper, so that the older established industry is threatened with extinction. This synthetic methanol is also made by a catalytic process: carbon monoxide and hydrogen are heated in the presence of zinc oxide, the catalyst.

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Needless to add, temperature and pressure conditions have to be very carefully regulated, and this involves using abstract scientific principles.

A problem in which, one is tempted to add, every industrial chemist is either active or interested, is the artificial production of rubber, which in our civilization, ranks with iron and steel and coal and oil in importance. Rubber is still obtained practically exclusively from the rubber tree, but signs are not wanting to indicate that the artificial production of rubber in the chemist's laboratory may not be very far distant. At any rate, rubber-like substances have been obtained from isoprene, a hydrocarbon which can be obtained from turpentine, petroleum, etc.; and what is even more significant, isoprene changes into "rubber" only in the presence of some catalyst. Sodium has been one of the catalysts used. It is not impossible that the success of the process hinges very largely upon the discovery of the appropriate catalyst. And, it might be added in conclusion, that certain inorganic and organic substances "accelerate" the combination of sulphur and rubber to form the indispensable vulcanized rubber.

We have said that we have, as yet, no satisfactory

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theory of catalytic action, but there are hypotheses to explain such action in certain cases. A very general assumption is made that the catalyst causes a concentration upon its surface of the reacting molecules; and the greater the number of molecules per unit of volume, the more likelihood is there for chemical reaction taking place. Again, experiments by Langmuir of the General Electric Company, and by Taylor of Princeton University, point to the probability that in certain instances at least the function of the catalyst is to convert inactive molecules into active atoms. For example, nitrogen as N_2 is the molecule and comparatively inactive in the chemical sense; whereas nitrogen as N is the atom and is quite active. Somewhat the same is true of hydrogen the molecule, H_2 , versus hydrogen the atom, H . We have evidence for believing that the catalyst used to accelerate the combination of nitrogen and hydrogen to form ammonia, does so by facilitating the decomposition of molecules into atoms, the atoms, in turn, readily combining. The reaction may be pictured by making use of the following chemical equations:



CHAPTER XXIV

CHEMISTRY IN AMERICA

CHEMISTRY in America is a very young science. It probably received its impetus from the Englishman, Priestley, the discover of oxygen, who came to these shores in the early part of the last century, and from Robert Hare, the inventor of the oxyhydrogen blowpipe. The flame was kept a-burning by a succession of well-known teachers at Harvard and Pennsylvania, among whom may be mentioned Cooke and Wolcott Gibbs. The more modern period was ushered in by Charles Eliot in Boston, Ira Remsen at Johns Hopkins, Frederick Chandler at Columbia, and E. F. Smith at Pennsylvania.

From small beginnings, the science has enlarged a thousandfold. The American Chemical Society has a membership of over 15,000. It publishes an erudite journal, devoted to recording the results of research by its members; a journal of chemical abstracts embracing a digest of the world's chemical literature;

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and an industrial journal which, in the last four or five years, has become unrivaled.

Some of our leading chemists received their post-graduate training in Germany. These men are making use of their training. Apart from their immediate services to the government, these men have, during the last twenty-five years, trained the younger generation to a degree which has called forth the admiration of their German masters. Even before the war, the number of American chemists at German universities showed a marked falling off. The post-graduate departments at Harvard, at Chicago, at California, at Columbia, at Johns Hopkins, at Yale, at Michigan, and others, have become the serious rivals of those at Berlin and Munich, Bonn and Heidelberg.

The chemical advisers of the government are directing, and the larger body of chemists is actively engaged in, work on explosives, on gases, on foods, on iron and steel, on copper, on aluminum, on fertilizers, on dyes, on drugs, on rubber, on leather, on paints, on glass, on fats and soaps, on paper, on cement, etc.

In the mathematical branch of the science—that

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more particularly concerned with the fundamental properties of matter—we lead many countries.

Willard Gibbs of Yale, one of the profoundest mathematical physicists of the century, was the fore-runner. Closely following upon him came Edward Morley, of Western Reserve University, whose work on the composition of water is among the classics of chemistry. Then came T. W. Richards, Harvard, winner of the Nobel Prize, and the great authority on the weight relationships of the elements; G. N. Lewis, California, the energy exponent and worker in many fundamental physico-chemical problems; H. N. Harkins, Chicago; W. D. Bancroft, Cornell; etc. Closely associated with these, but particularly well known as the authors of successful text-books, may be mentioned Alexander Smith, Columbia, and Julius Stieglitz, Chicago.

In the analytical field, in the detection and in the estimation of the elements and their compounds, we have, or have had, F. W. Clarke, of the U. S. Geological Survey, particularly well known for his work on chemical geology; F. A. Gooch, Yale, originator of several well-known appliances in the laboratory; W. F. Hillebrand, U. S. Geological Survey,

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the author of a splendid work on rock analysis; etc.

In the field of organic chemistry we have M. Gomberg, Michigan, who has developed a new branch of organic chemistry; Roger Adams, Illinois, a splendid synthetic chemist; J. M. Conant, Harvard, who has often applied physical chemistry to the elucidation of organic chemical problems; C. S. Hudson, U. S. Bureau of Standards, a great authority on the chemistry of sugar; W. A. Noyes, Illinois; M. T. Bogert, Columbia; J. M. Nelson, Columbia; T. B. Johnson, Yale; etc. This branch of the science suffered a grievous loss some time ago by the death of J. U. Nef, Chicago.

Again, in the most recent offshoot of organic chemistry, the application of the science to physiology, to biology and to medicine in general, there are many names of first rank. There come to mind the names of such men as O. Folin, Harvard, who has revolutionized clinical chemistry; P. A. Levene and D. D. Van Slyke, Rockefeller Institute; R. H. Chittenden and L. B. Mendel, Yale; E. V. McCollom and W. Jones, Johns Hopkins; W. J. Gies, Columbia; H. D. Dakin, K. G. Falk, G. Lusk and S. R. Benedict, Cornell; etc.

As might be expected, in the industrial field, where

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the inventive genius finds an immediate and successful outlet, the American chemist has performed miracles. Every student who has taken a course in elementary chemistry knows the story of how Good-year vulcanized rubber, how Hall revolutionized the manufacture of aluminum, how Frasch devised an ingenious method for extracting sulphur from the Louisiana ores, how Castner invented his electrolytic process for the production of caustic soda, how Acheson discovered carborundum, artificial graphite and deflocculated graphite, and how Baekeland made "bakelite," etc.

A most encouraging augury for the future is the close coöperation that is beginning to exist between the great industries, on the one hand, and the universities on the other. For much of this our thanks are due to the late R. K. Duncan, the director of the Mellon Institute of Pittsburgh, and the originator of the Mellon Institute Fellowships. An even better sign of the times is found in the research laboratories that our industrial concerns are establishing. A model of its kind is the general laboratory of the General Electric Co. Its two chief chemists, W. R. Whitney and I. Langmuir, are among the leaders of their profession in this country.

REFERENCES

THE beginner can do no better than to start the study of the subject by reading and studying some elementary text on chemistry, preferably of high-school grade. There are a number of such books, for example:

Beginning Chemistry, by Fletcher, Smith and Harrow (American Book Co.).

Elementary Principles of Chemistry, by Brownlee, Fuller, Hancock, Sohon and Whitsit (Allyn and Bacon).

Practical Chemistry, by Black and Conant (Macmillan).

He may next read very appropriately one or more of a number of "popular" treatises, in which much of chemistry is told in an attractive form by men who can write and by men who are competent. Among such books are:

Chemistry in the Service of Man, by Findlay (Longmans).

Creative Chemistry, by Slosson (Century).

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The Story of Chemistry, by Darrow (Bobbs-Merrill).

Chemistry and the Home, by Howe and Turner (Scribner).

Chemistry in Modern Life, by Arrhenius (Van Nostrand).

Chemistry in the World's Work, by Howe (Van Nostrand).

The reader or student is now in a position to dip into some history, if he wants to. Without referring him to any "big" volumes, he can read with pleasure any one of the following:

A History of Chemistry, by Moore (McGraw-Hill).

History of Chemistry, by Thorpe (Van Nostrand).

A Concise History of Chemistry, by Hilditch (Van Nostrand).

A History of Chemistry, by Armitage (Longmans).

Historical Introduction to Chemistry, by Lowry (Macmillan), has particular merit, because the author traces much of chemical history by liberal quotations from the writings of the makers of chemistry.

Of chemical biographies there are a number, but

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far from enough. First of all we mention a few books, each one of which deals with a number of famous chemists. There are:

Famous Chemists, by Tilden (Dutton).

Essays in Historical Chemistry, by Thorpe (Macmillan).

Eminent Chemists of Our Time, by Harrow (Van Nostrand).

The English Chemical Society has published two excellent volumes entitled *Memorial Lectures Delivered Before the Chemical Society* (Gurney and Jackson, London), but, unfortunately, they are rather difficult to get hold of.

Individual biographies are few and far between, and many of them have either not been translated into the English language, or are very rare and difficult to obtain. Some of those which are available and very illuminating are:

John Dalton, by Roscoe (Macmillan).

The Life of Pasteur, by René Vallery-Radot (Doubleday, Doran).

The Life of Sir William Crookes, by Fournier D'Albe (Appleton).

Sir William Ramsay, by Tilden (Macmillan).

Pierre Curie, by Marie Curie (Macmillan).

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The Sceptical Chemist by Boyle (in the Everyman's Library, published by Dutton), while essentially a treatise on the state of chemistry in the seventeenth century, contains much of a historical and somewhat autobiographical character; and it is, incidentally, written by one of the "fathers" of modern chemistry.

Now is the time to begin studying chemistry in real earnest. General chemistry, essentially inorganic chemistry, is treated in such standard books as:

General Chemistry, by Deming (Wiley).

Smith's Inorganic Chemistry, by Kendall (Century).

Modern Inorganic Chemistry, by Mellor (Longmans).

The above increase in difficulty as we go from Deming to Mellor.

From inorganic we may go to organic chemistry, and some books which can be recommended are:

Organic Chemistry, by Conant (Macmillan).

An Introduction to Organic Chemistry, by Lowy and Harrow (Wiley).

An Introduction to Organic Chemistry, by Williams (Van Nostrand).

A Text Book of Organic Chemistry, by Chamberlain (Blakiston).

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The analytical methods used in chemistry are found in many books. I merely select the most modern texts in which laboratory directions are accompanied by ample theoretical discussions:

The Elements of Qualitative Analysis, by Stieglitz (Century).

Inorganic Quantitative Analysis, by Fales (Century).

The Methods of Organic Chemistry, by Porter, Stewart and Branch (Ginn).

The subject of physical chemistry is well treated for a beginner's needs in *Outlines of Theoretical Chemistry*, by Getman (Wiley); that of biochemistry in *Introduction to Physiological Chemistry*, by Bodansky (Wiley); and that of industrial chemistry in *Elements of Industrial Chemistry*, by Rogers (Van Nostrand).

One or two miscellaneous books may be added:

Atoms and Rays, by Lodge (Doubleday, Doran).

The Romance of the Atom, by Harrow (Live-right).

The ABC of Atoms, by Russell (Dutton).

Chemistry in Medicine, edited by Stieglitz (Chemical Foundation, 85 Beaver Street, N. Y.).

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A good current journal for keeping up with chemistry is the *Journal of Chemical Education* (654 Madison Avenue, New York); and for more advanced reading, the *Journal of the American Chemical Society*, and *Industrial and Engineering Chemistry*, both of which can be obtained from the Secretary's office, Mills Building, Washington, D. C.

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